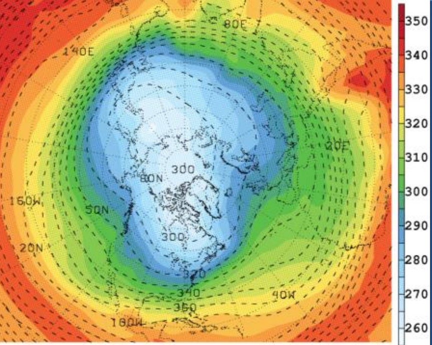
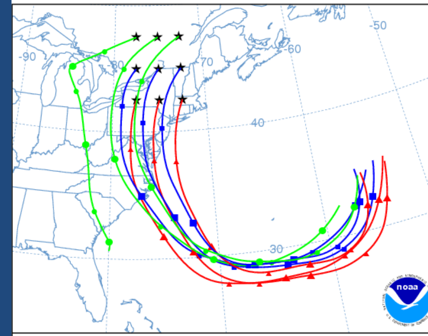
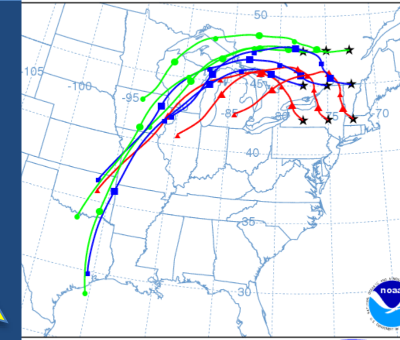






Atmospheric Rivers over eastern Canada: Their seasonality, impact on air mass dynamics, and links to extreme precipitation

John Gyakum, Alice Wood, Eyad Atallah

Department of Atmospheric and Oceanic Sciences

McGill University

Shawn Milrad

Meteorology Program

Embry-Riddle Aeronautical University

2016 International Atmospheric Rivers Conference

Scripps Institution of Oceanography; August 11, 2016

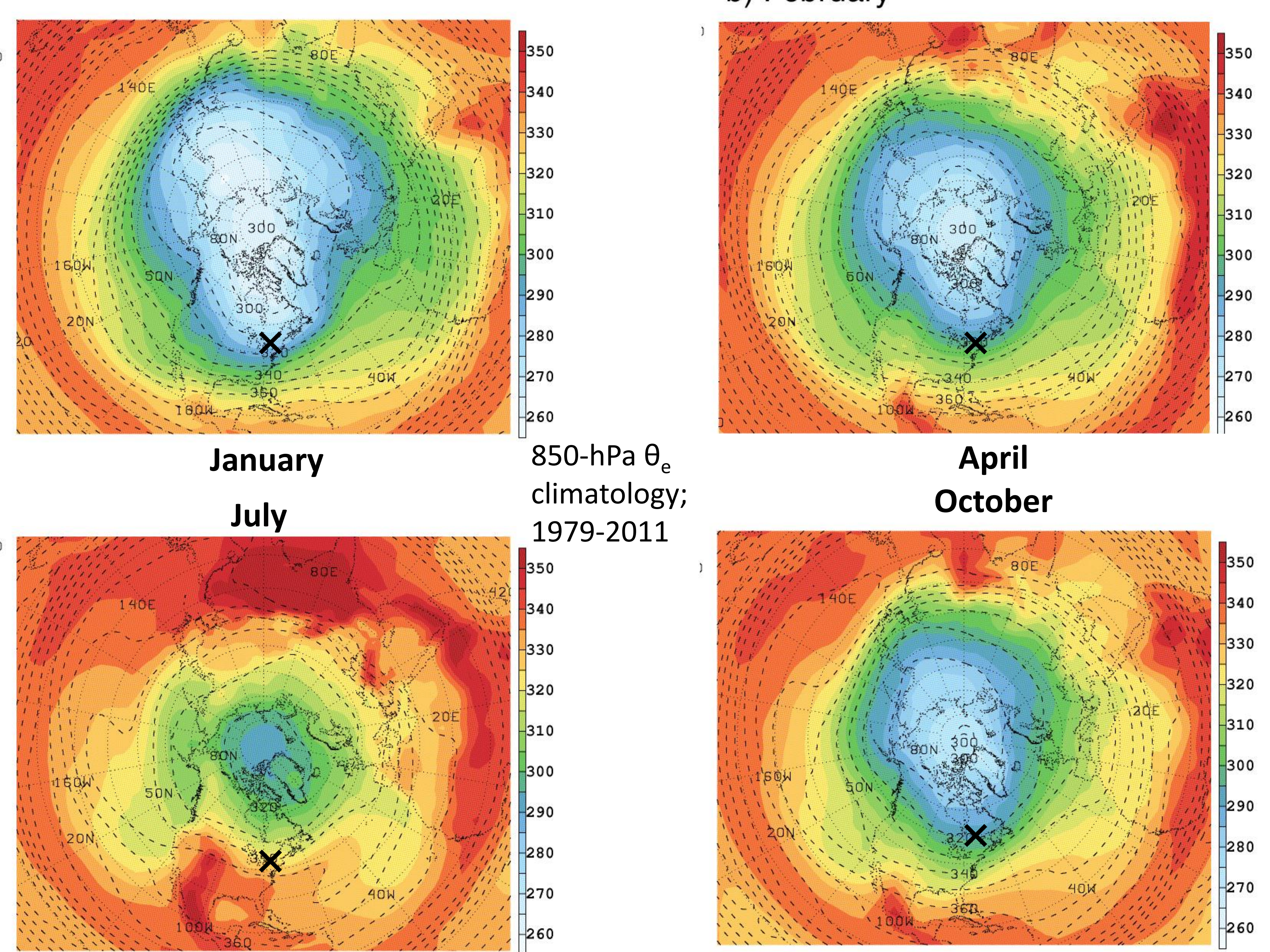
McGill

NSERC CRSNG

CNRCWP

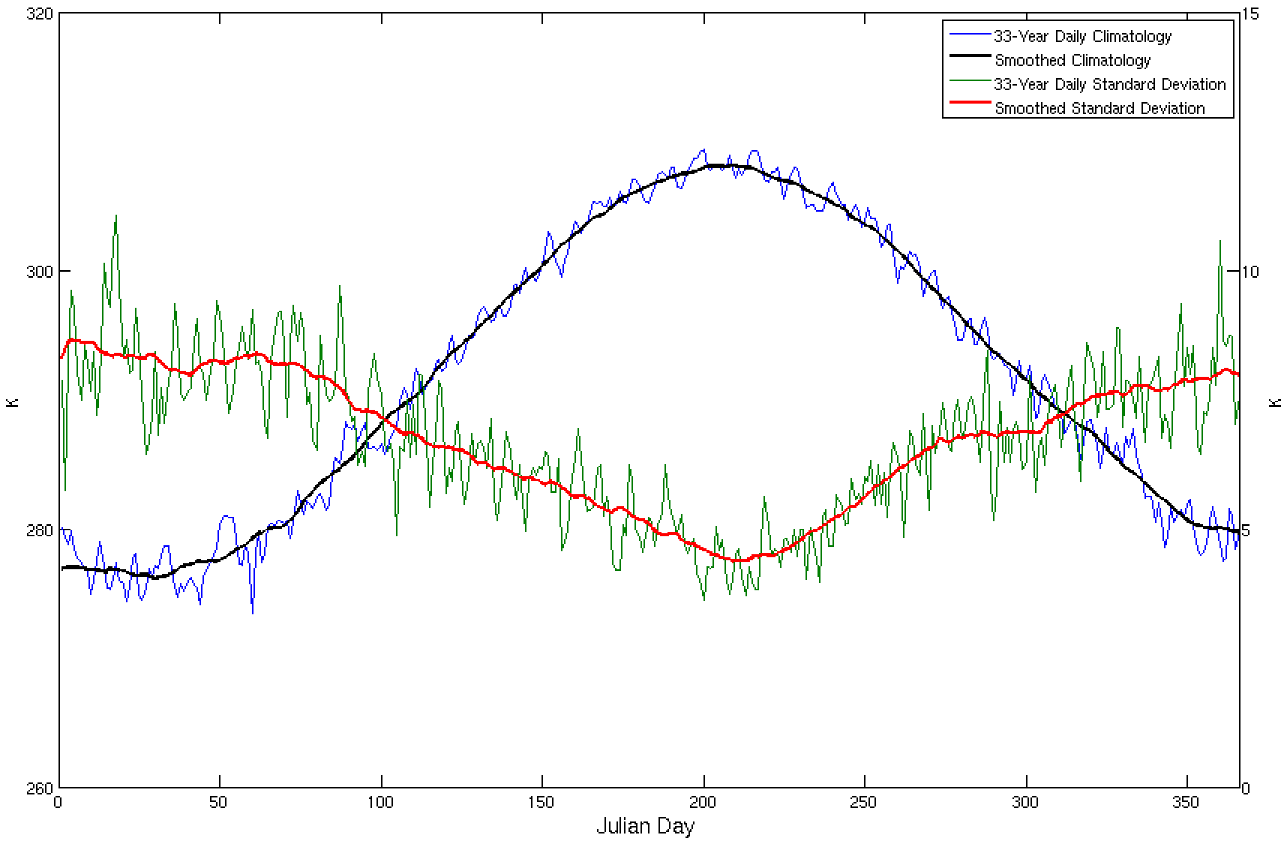
Why should we focus on air masses (in particular, lower tropospheric θ_e) ?

- Air masses are a fundamental quantity in both weather and climate.
- The lower boundary of the coupling index (θ_e difference between lower (850 hPa and dynamic tropopause), or convective stability
- A crucial thermodynamic property that modulates the rate of precipitation.
- θ_e is a conservative quantity.



January
April
July
October
850-hPa θ_e climatology; 1979-2011
80E
140E
20E
160W
80N
50N
20N
100W
40W
300
340
360
350
340
330
320
310
300
290
280
270
260

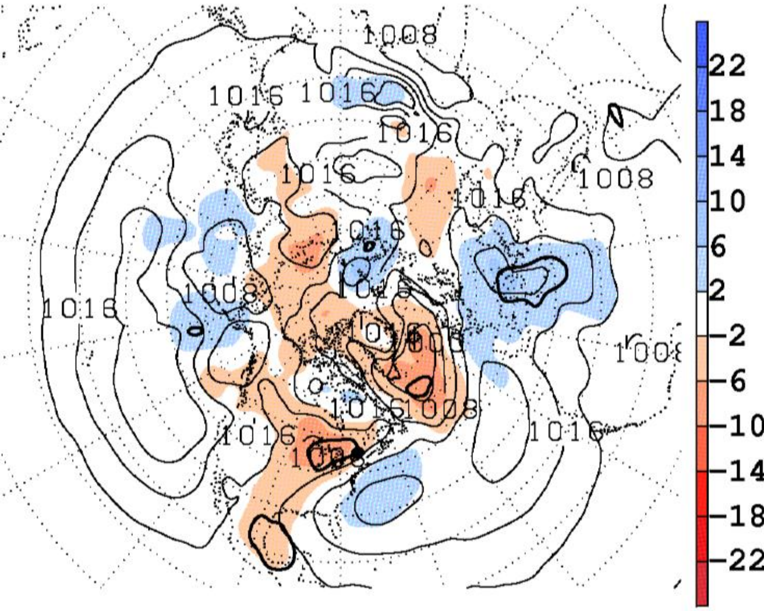
850-hPa θ_e climatology for Montreal from January 1 through December 31 (mean-blue; standard deviation-red)



Composites – Seasonal Extremes

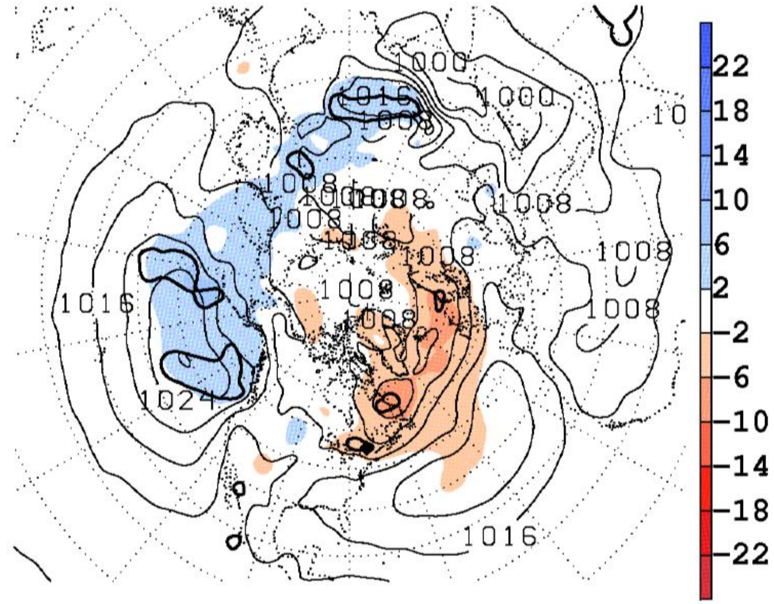
- Used NCEP (National Centers for Environmental Prediction) Reanalysis 2 from 1979-2011 to calculate θ_e. Applied 3-day running mean.
- Selected top 10 θ_e (DJF, MAM, JJA, SON) events by ranking cases based on their standardized anomalies.
- Created a 33-year weighted climatology based on the distribution of the extremes (e.g, for DJF, 3 in December, 4 in January, and 3 in February).
- Calculated anomalies relative to this weighted climatology, and computed their statistical significance.
- Created lag composites of various fields leading up to t = 0h which corresponds to the moment of peak θ_e for each case.
- Minimum thresholds were typically ~2 standard deviations above climatology (~16 K during DJF and ~10 K during JJA).

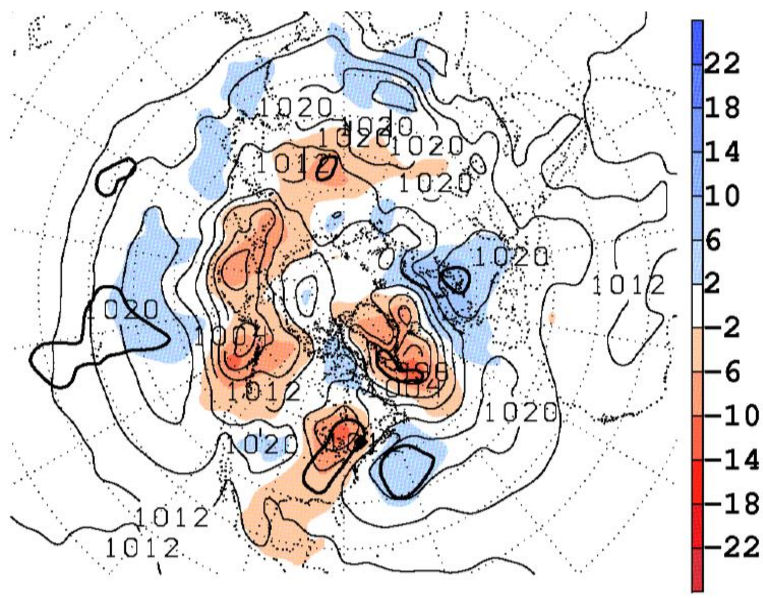
Composites of 10 most extreme cases of θ_e for Sea-level pressure (hPa, light contours), anomalies from climatology (hPa, shaded), and regions of anomaly exceeding the 99% confidence level (bold contours).



Spring (MAM)

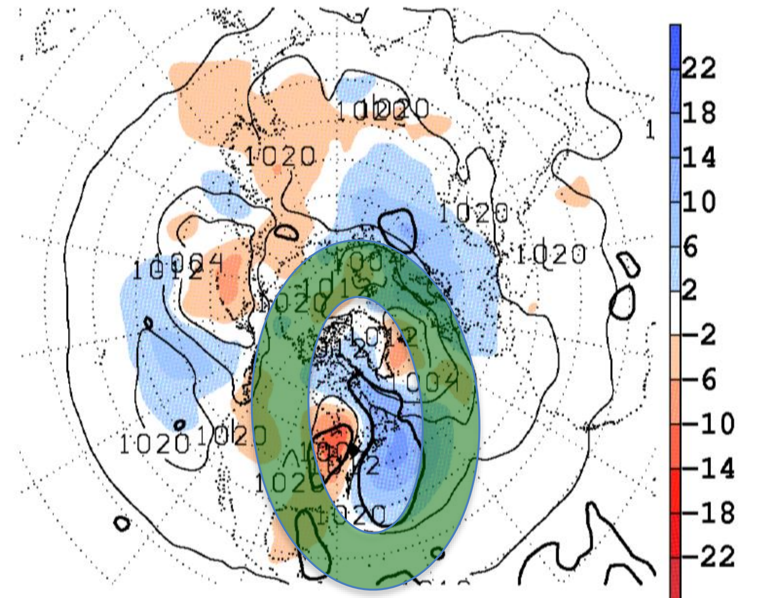
Summer (JJA)



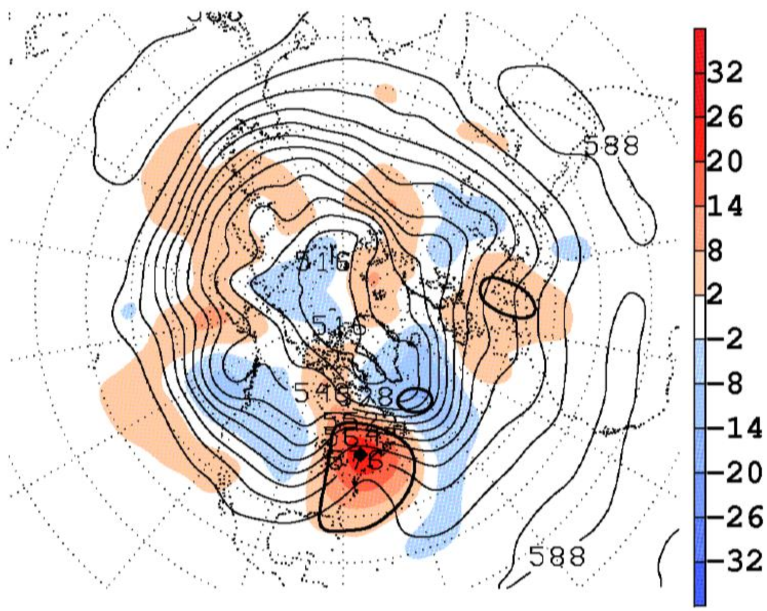


Autumn (SON)

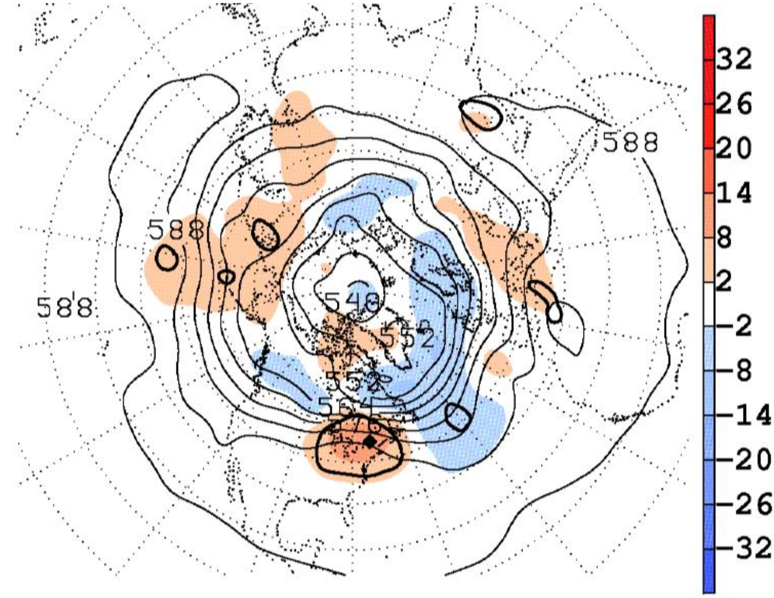
Winter (DJF)



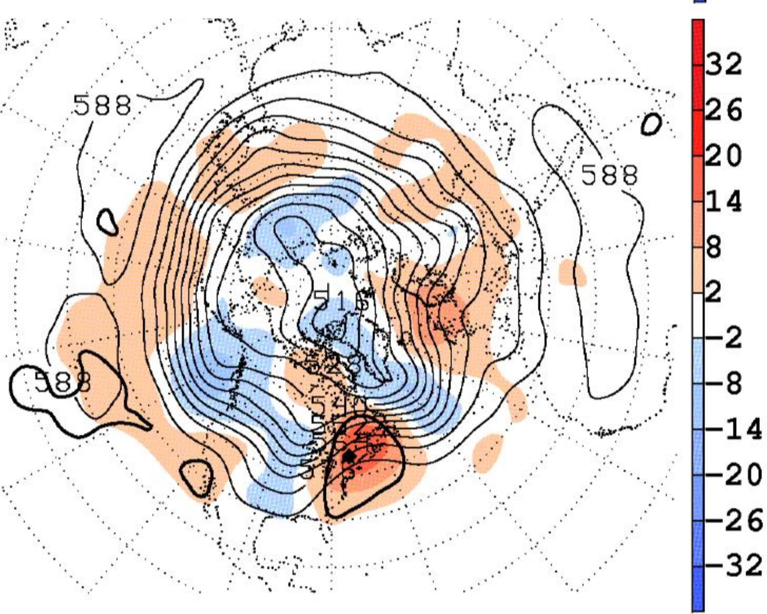
Composites of 10 most extreme cases of θ_e for 500-hPa heights (dam, light contours), anomalies from climatology (dam, shaded), and regions of anomaly exceeding the 99% confidence level (bold contours).



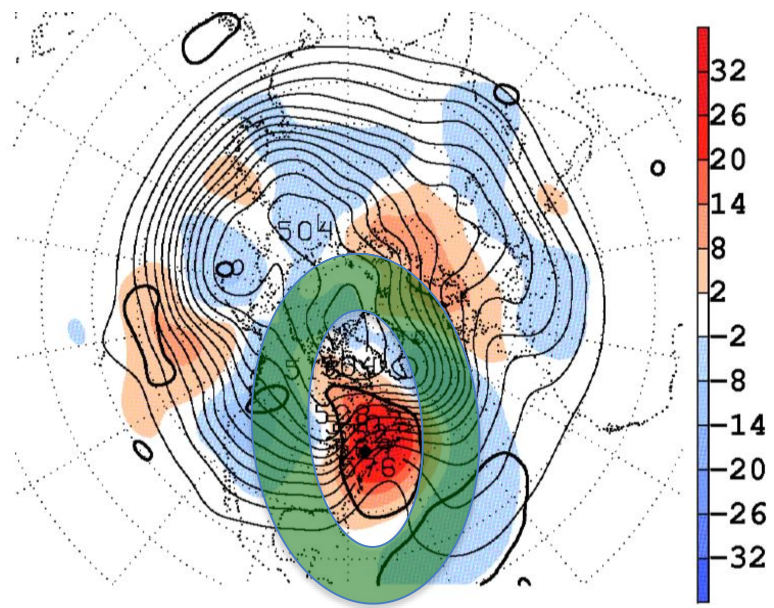
Spring (MAM)



Summer (JJA)

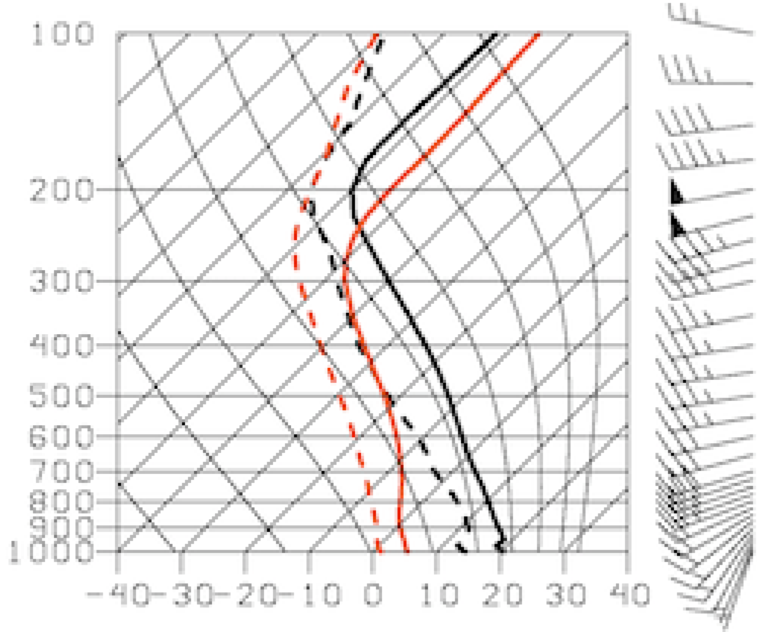


Autumn (SON)

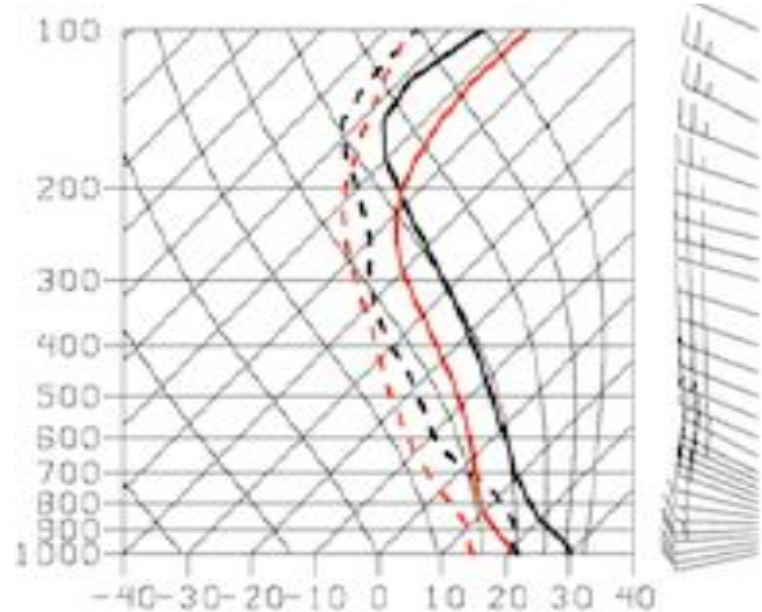


Winter (DJF)

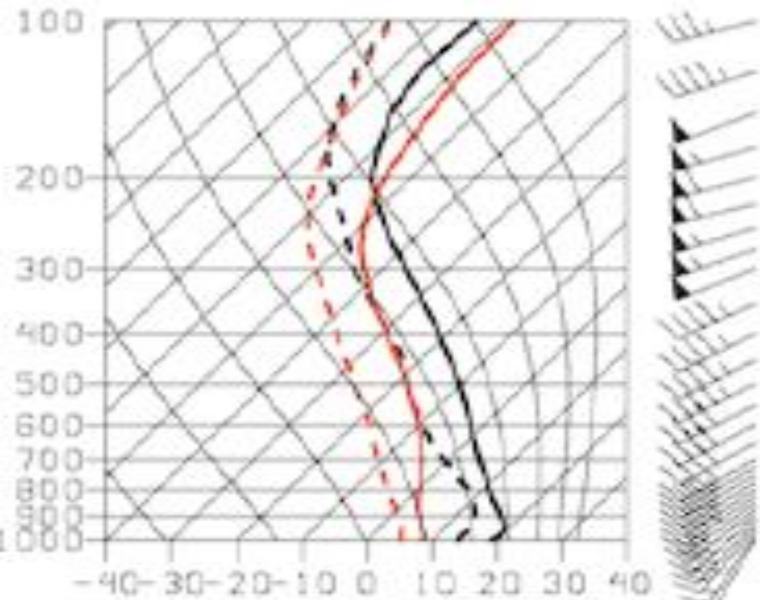
Composites of 10 most extreme cases of θ_e for soundings of temperature (deg C, solid), dewpoint (deg C, dashed), and wind. Climatological profiles are shown in red.



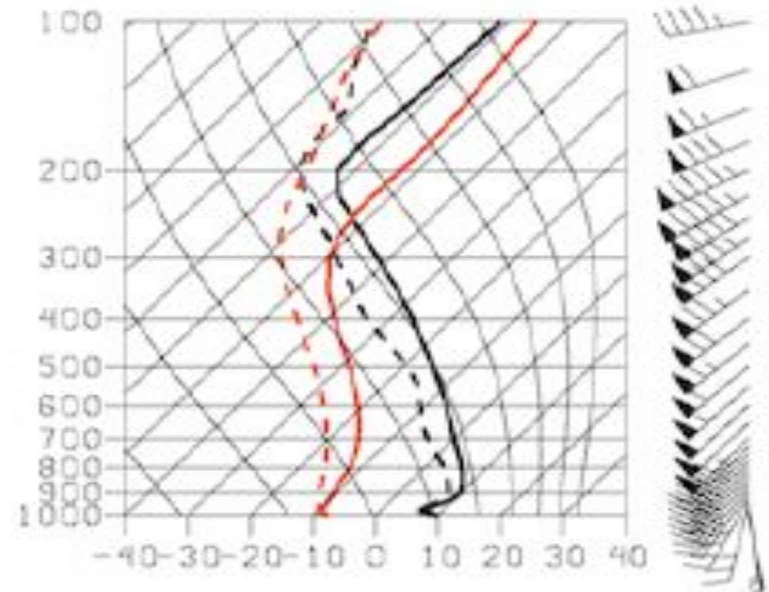
Spring (MAM)



Summer (JJA)

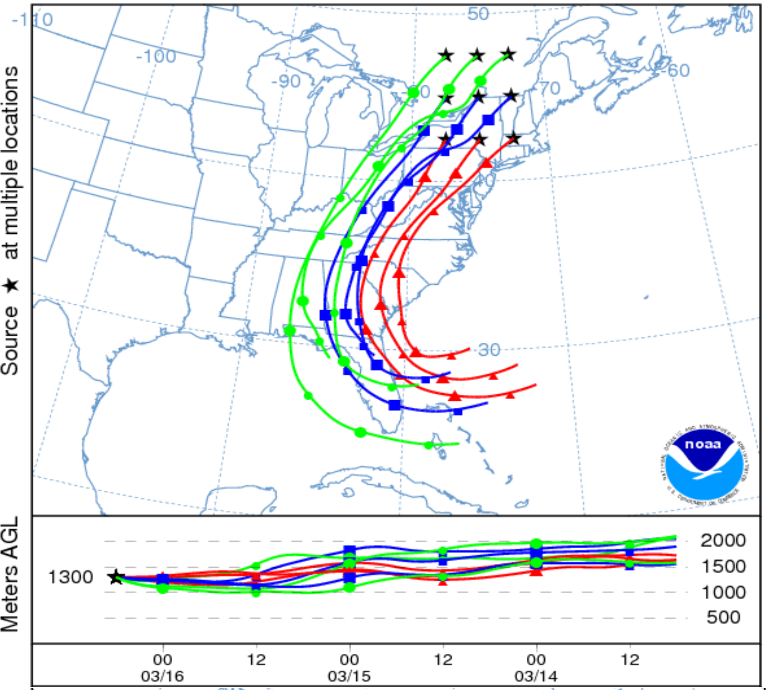


Autumn (SON)



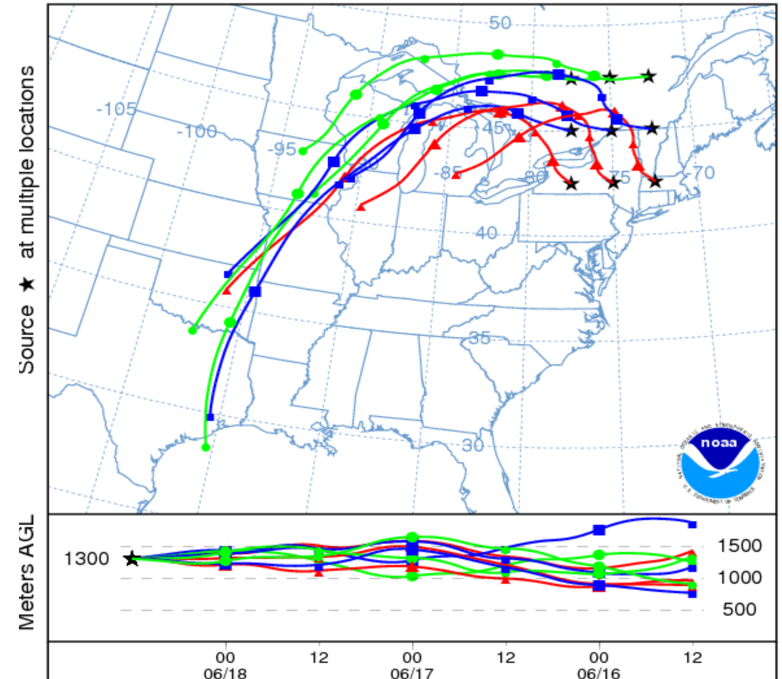
Winter (DJF)

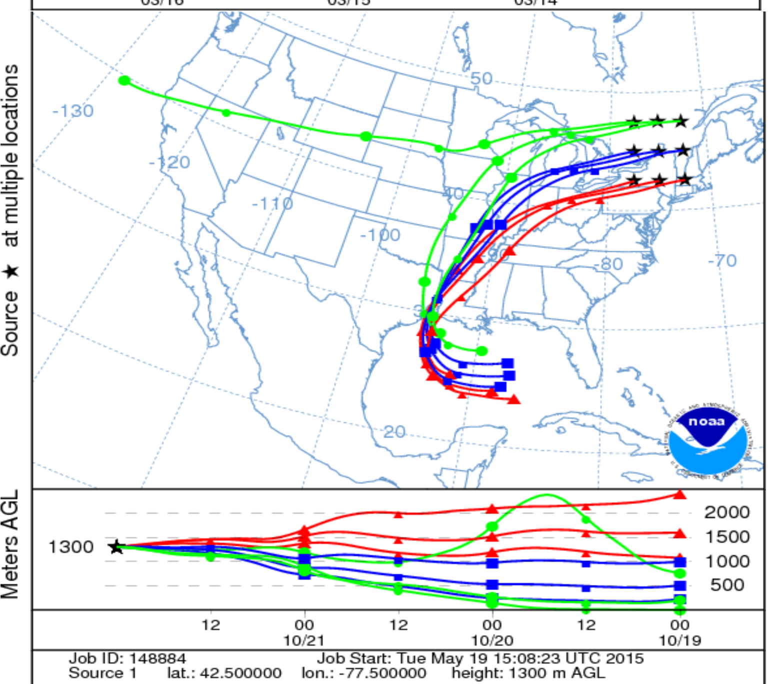
Composites of 10 most extreme cases of θ_e for back trajectories, ending in Montreal.



Spring (MAM)

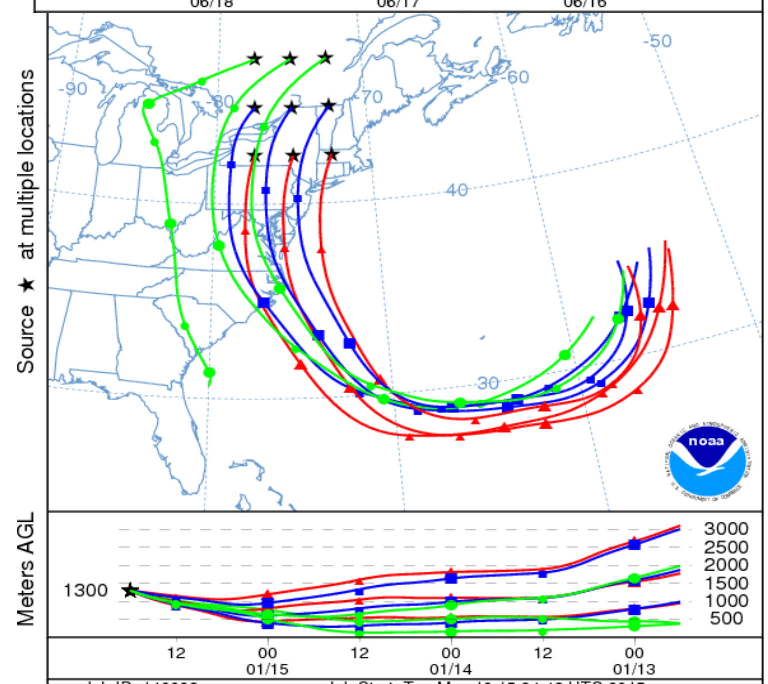
Summer (JJA)

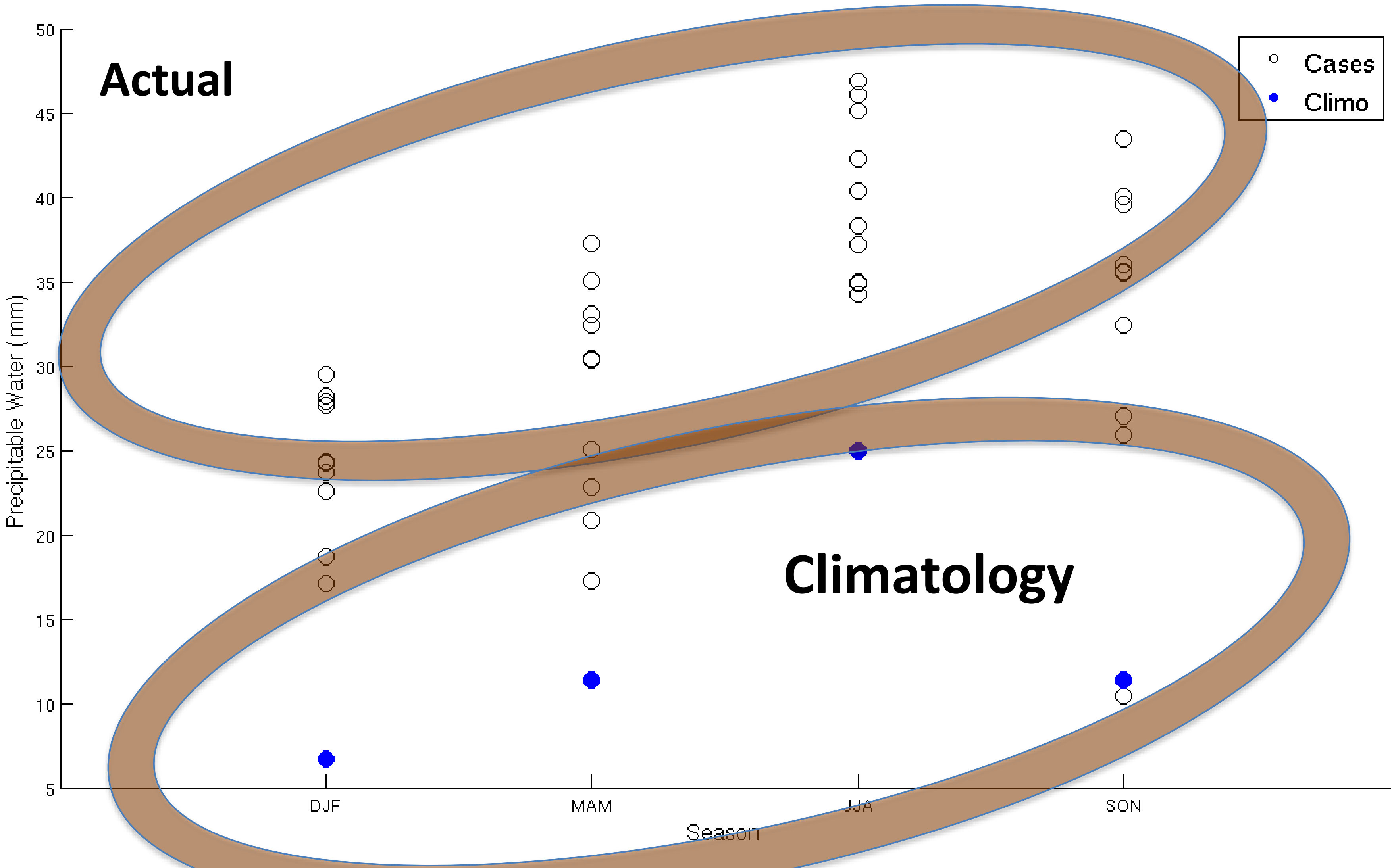




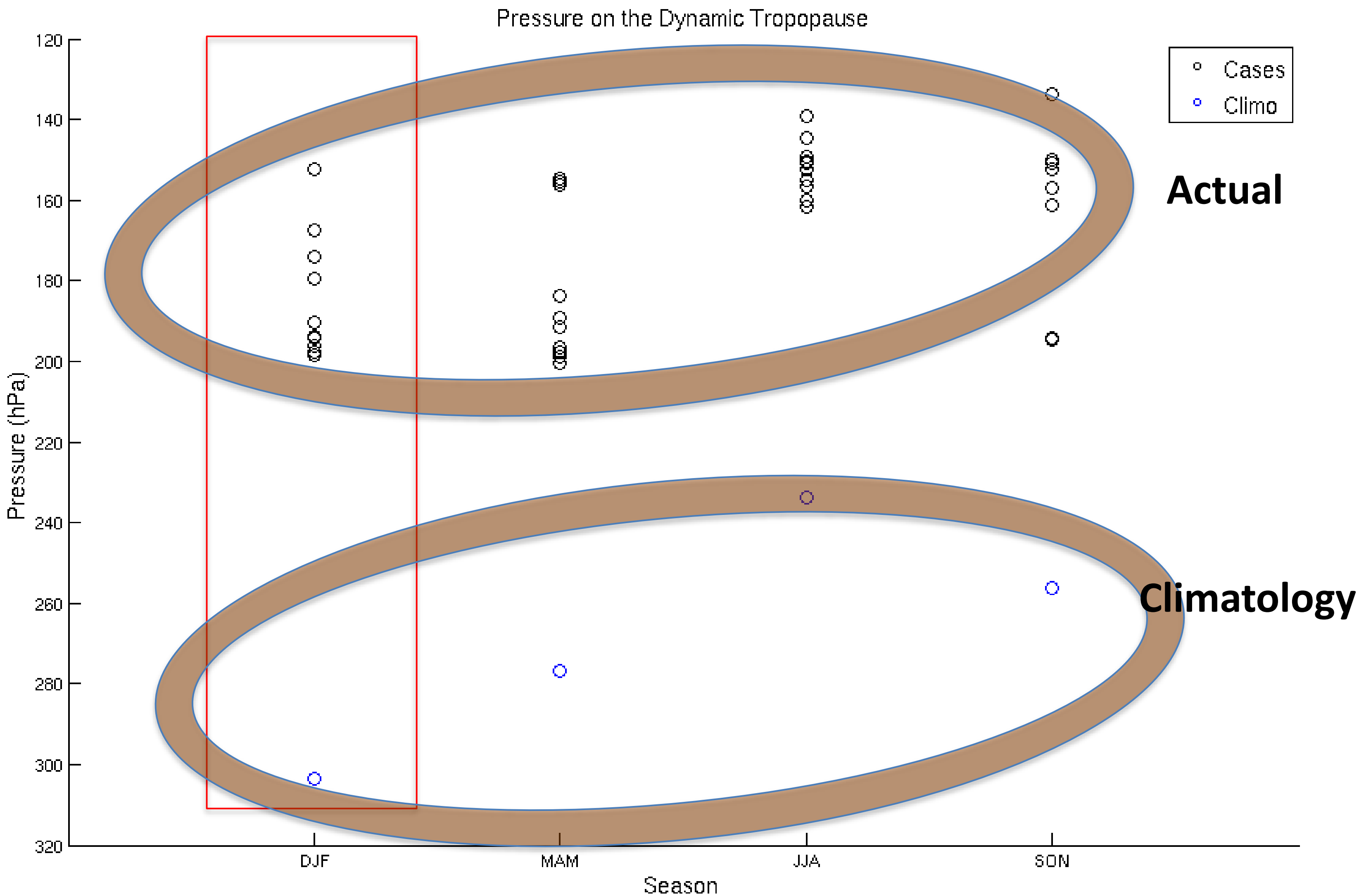
Autumn (SON)

Winter (DJF)





Precipitable water (mm; climatology-blue; extreme cases-open circles)


Pressure on the Dynamic Tropopause
Cases
Climo
Actual
Climatology
Pressure (hPa)
120
140
160
180
200
220
240
260
280
300
320
DJF
MAM
JJA
SON
Season

Relevance of extreme θ_e (air mass) to Extreme Precipitation)

- $P = \boldsymbol{R}D$, where P is the total precipitation, and $\boldsymbol{R}$ is the precipitation rate, averaged through the duration, D, of the event.
- At extreme values of θ_e, there is an exponential increase of precipitation rate, as a function of an incremental change in θ_e.
- **The air mass has much to do with the precipitation rate!**

The Precipitation Rate

- **From the notes of Fred Sanders and the tribute monograph (Gyakum 2008):**
  –

$$R = -\frac{1}{g}\int \omega \left(\frac{dr_s}{dp}\right)_{ma} dp$$

Precipitation Rate

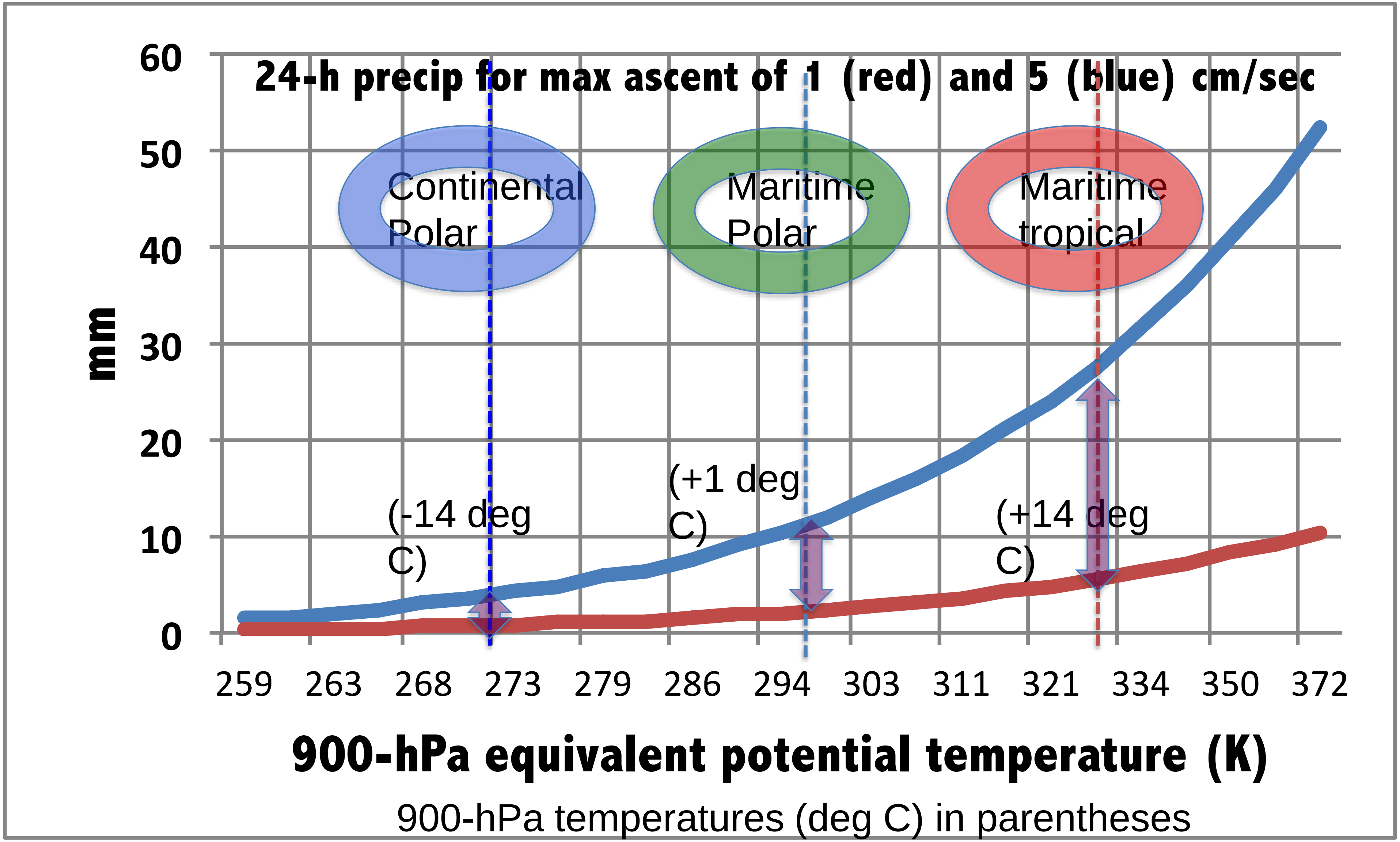
Vertical Motion

Change in saturated mixing ratio with height along the moist adiabat

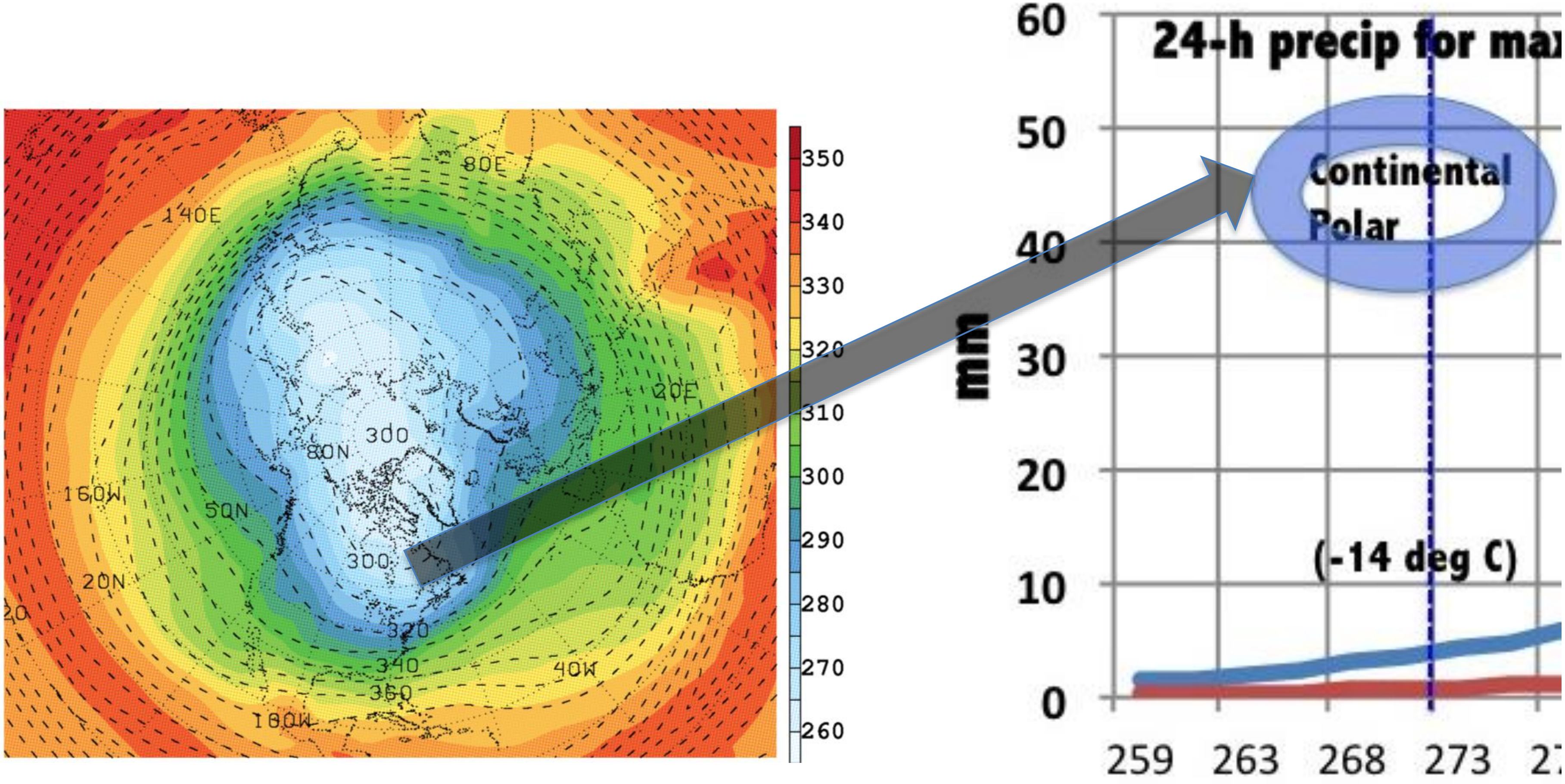
- **Ingredients within the equation**
  - **Lift**
  - **Temperature of the air mass**
  - **Static stability of the air mass (implicit within ω)**

P=Precipitation rate; g=gravity; **ω**=*dp/dt*; r_s =*saturation mixing ratio; ma = moist adiabat; p = pressure*

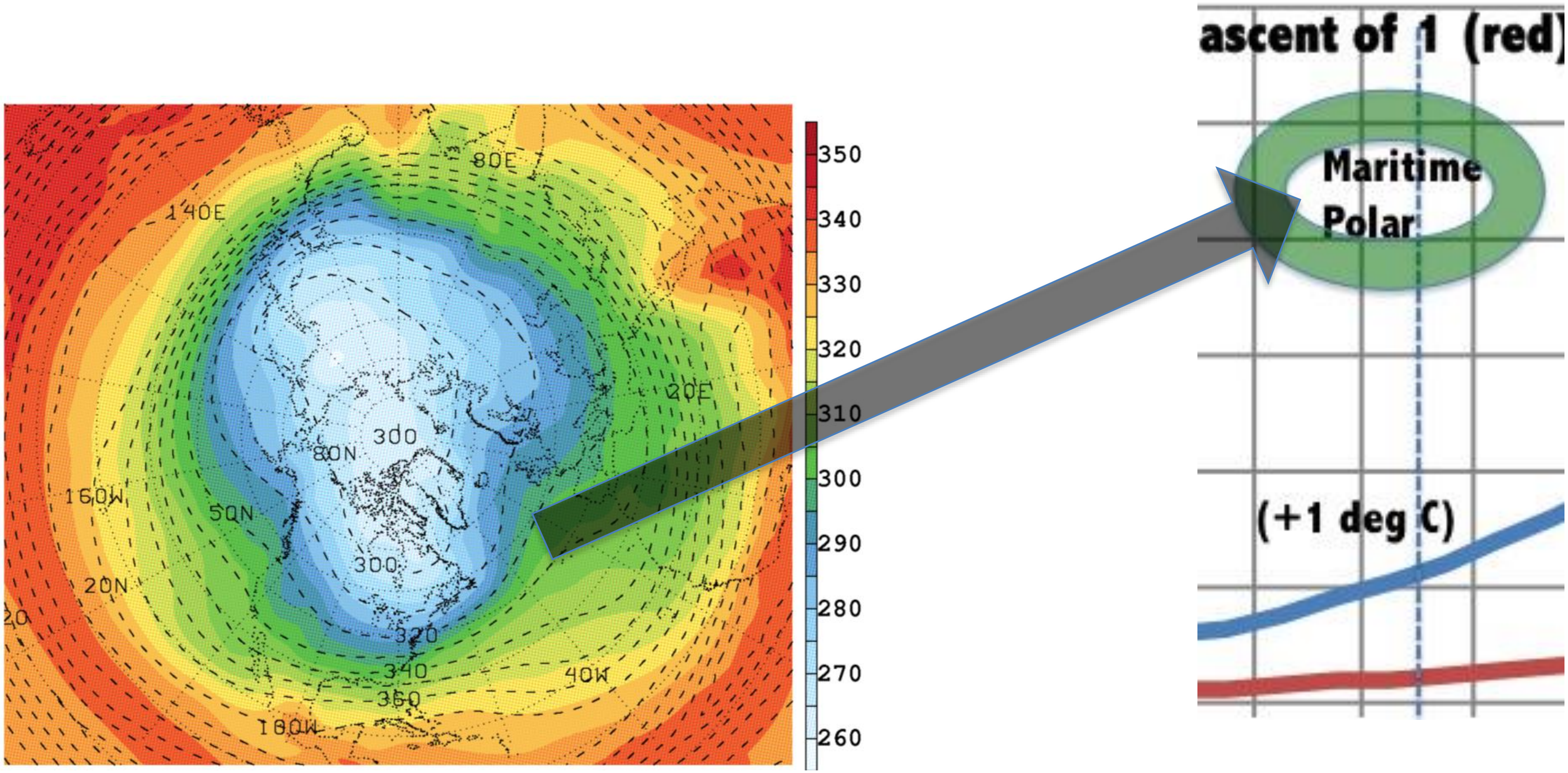
$$P = -\frac{1}{g}\int \omega \left(\frac{dr_s}{dp}\right)_{ma} dp$$



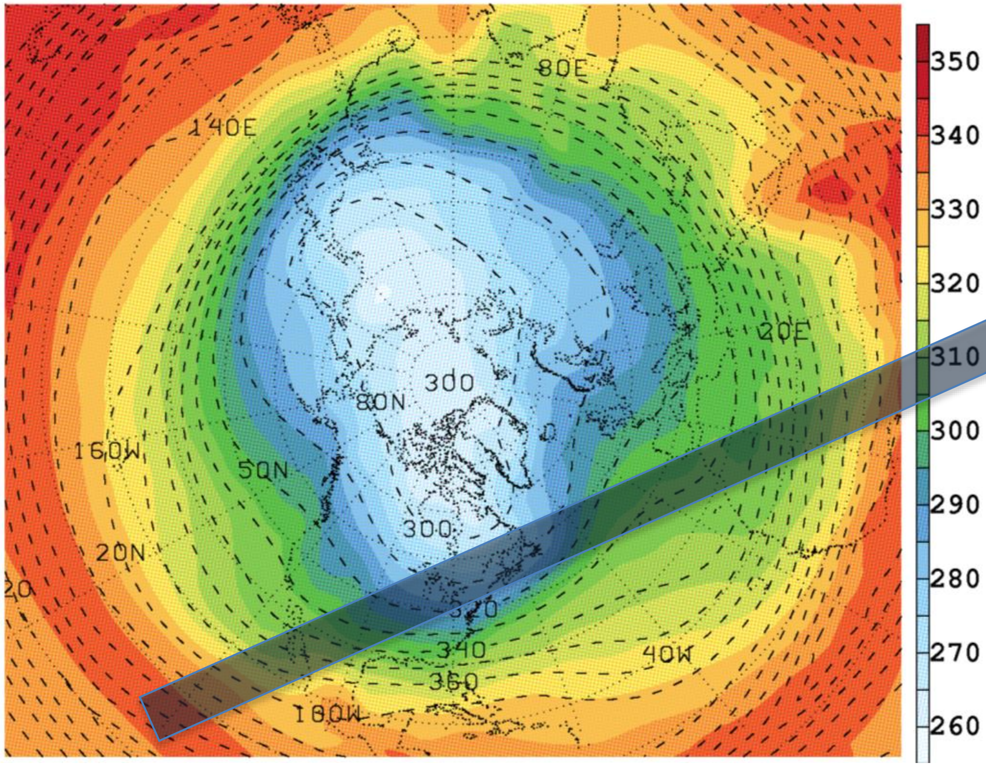
Consider the air mass climatology for January:

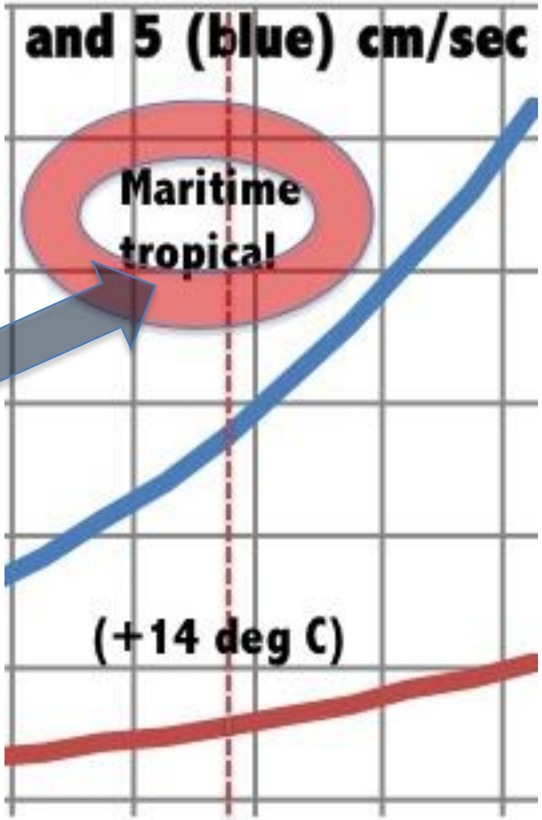


Consider the air mass climatology for January:



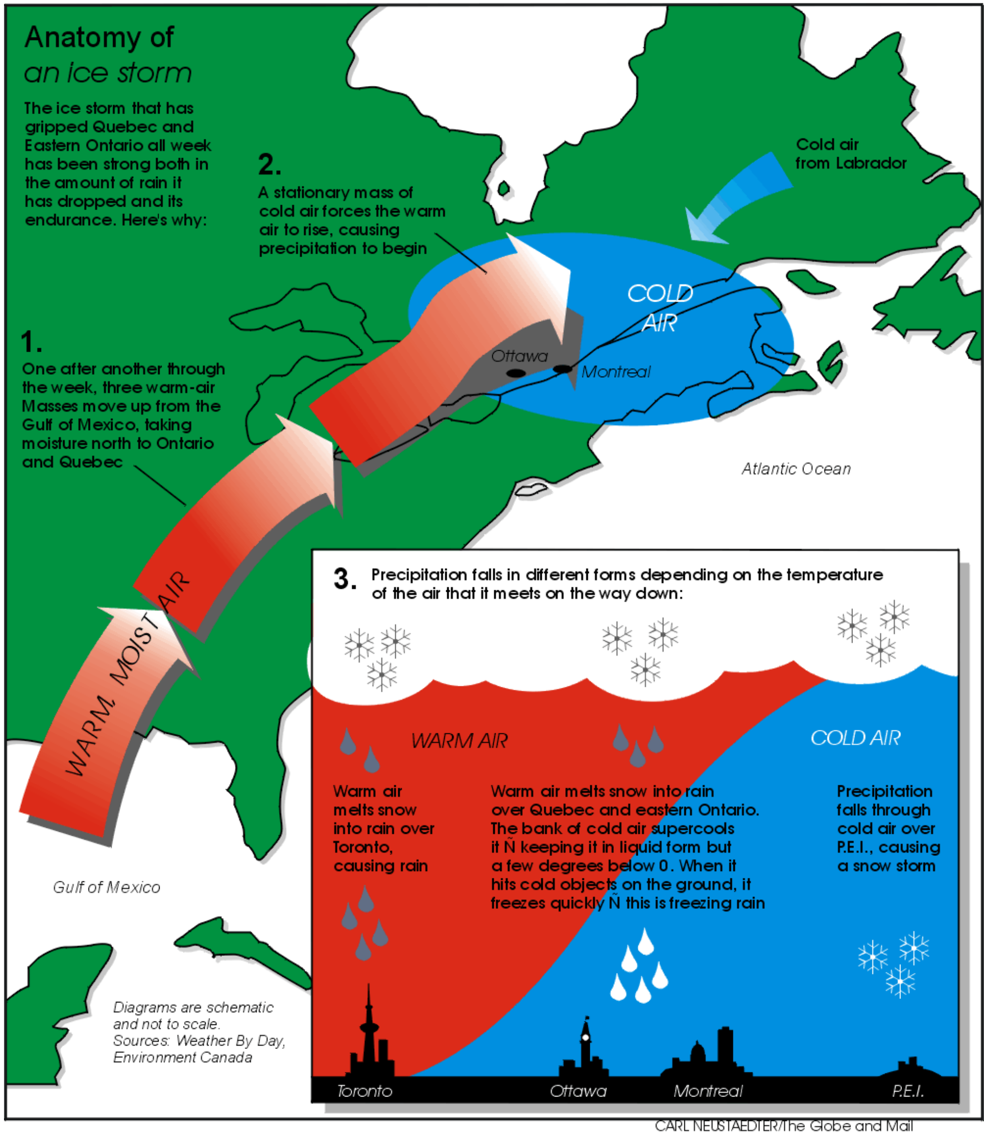
Consider the air mass climatology for January:





Consider the case of the Montreal Ice Storm of 5-9 January 1998:

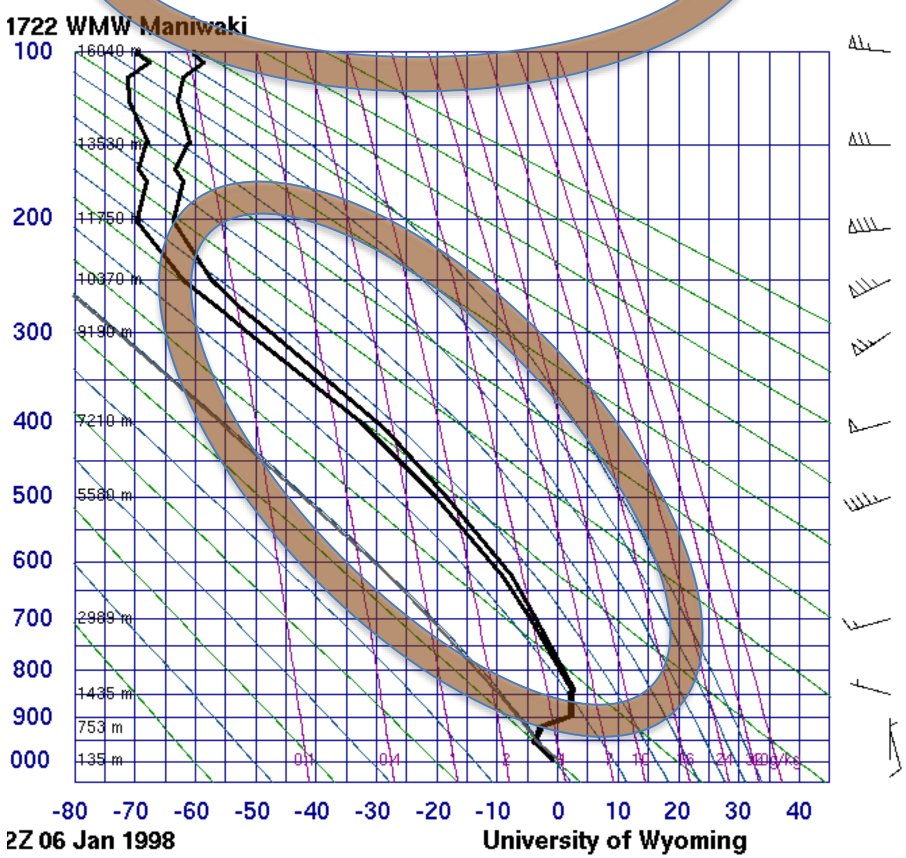
- **More than 125 mm of freezing rain accumulation during a 5-day period**
- **~$4 billion in damages**
- **More than 25 fatalities, mostly from hypothermia**
- **900,000 without power in Quebec, 100,000 without power in Ontario**

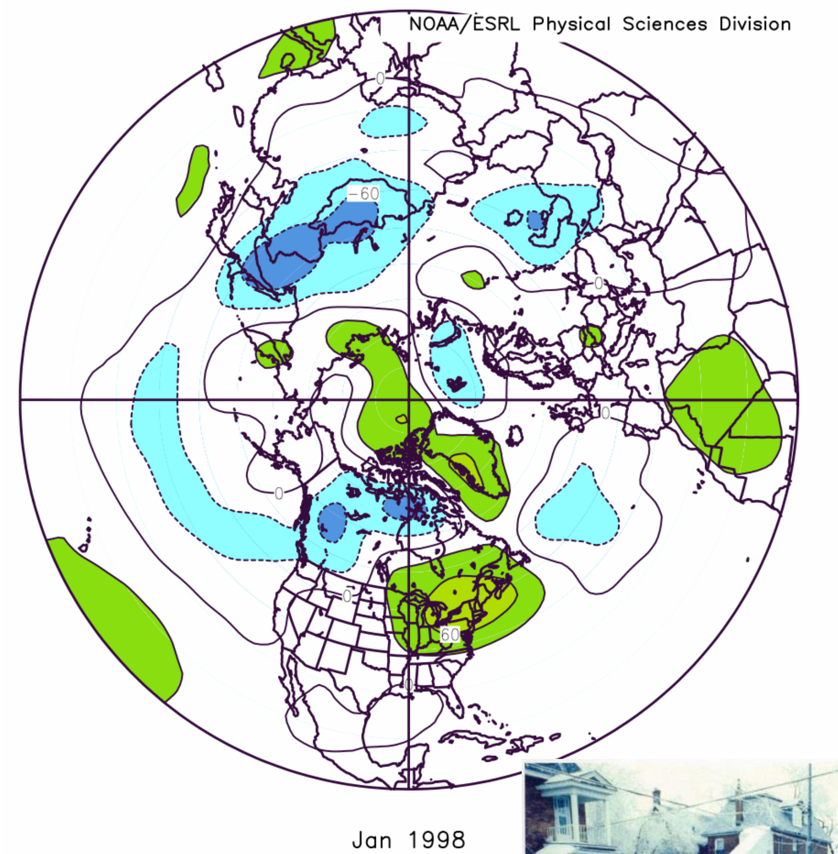


CARL NEUSTAEDTER/The Globe and Mail

Maniwaki (6 Jan; 1200 UTC) sounding and January 1998 1000-500 hPa thickness anomalies)

PW = 20.4 mm; climo = 6.5 mm

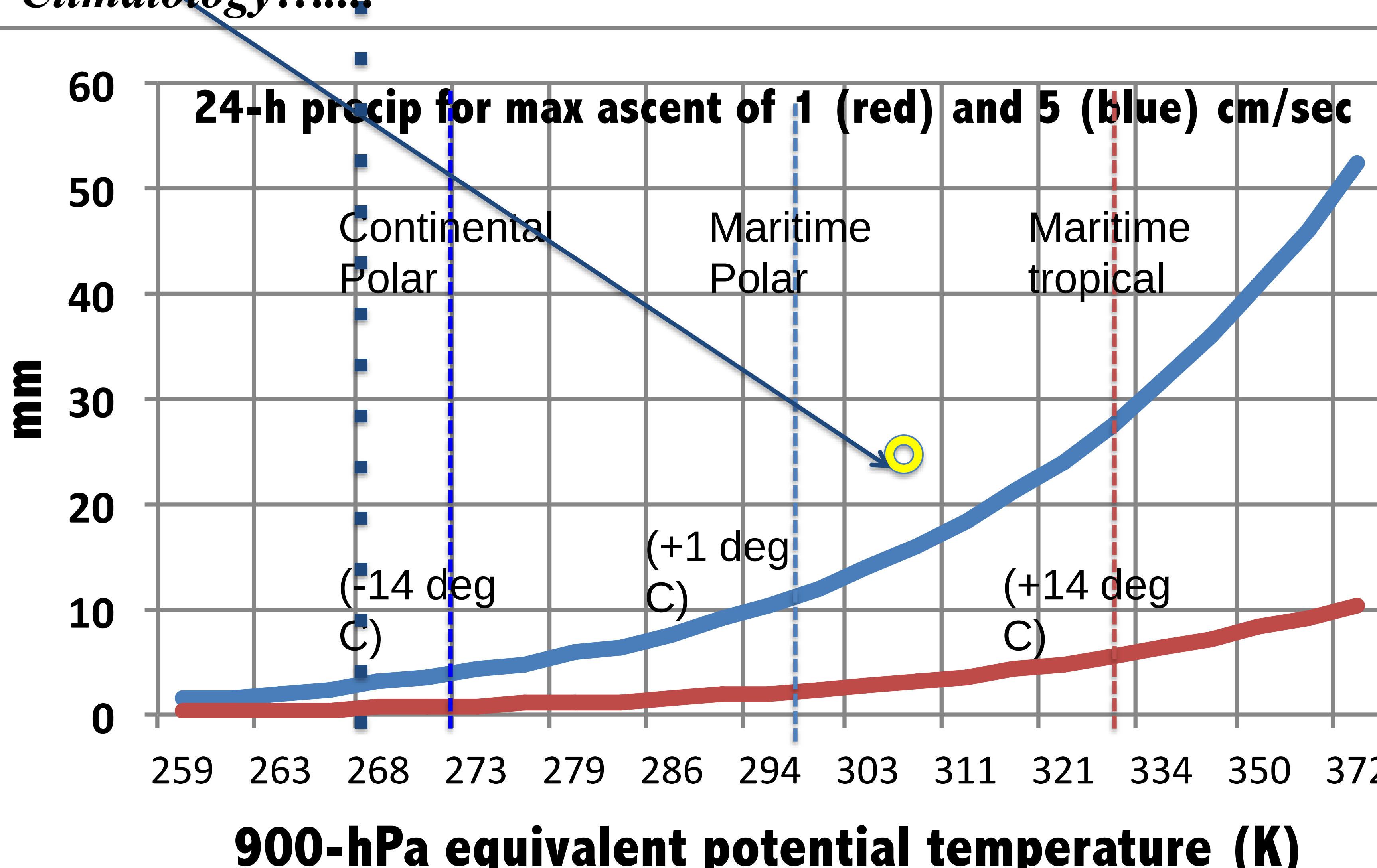




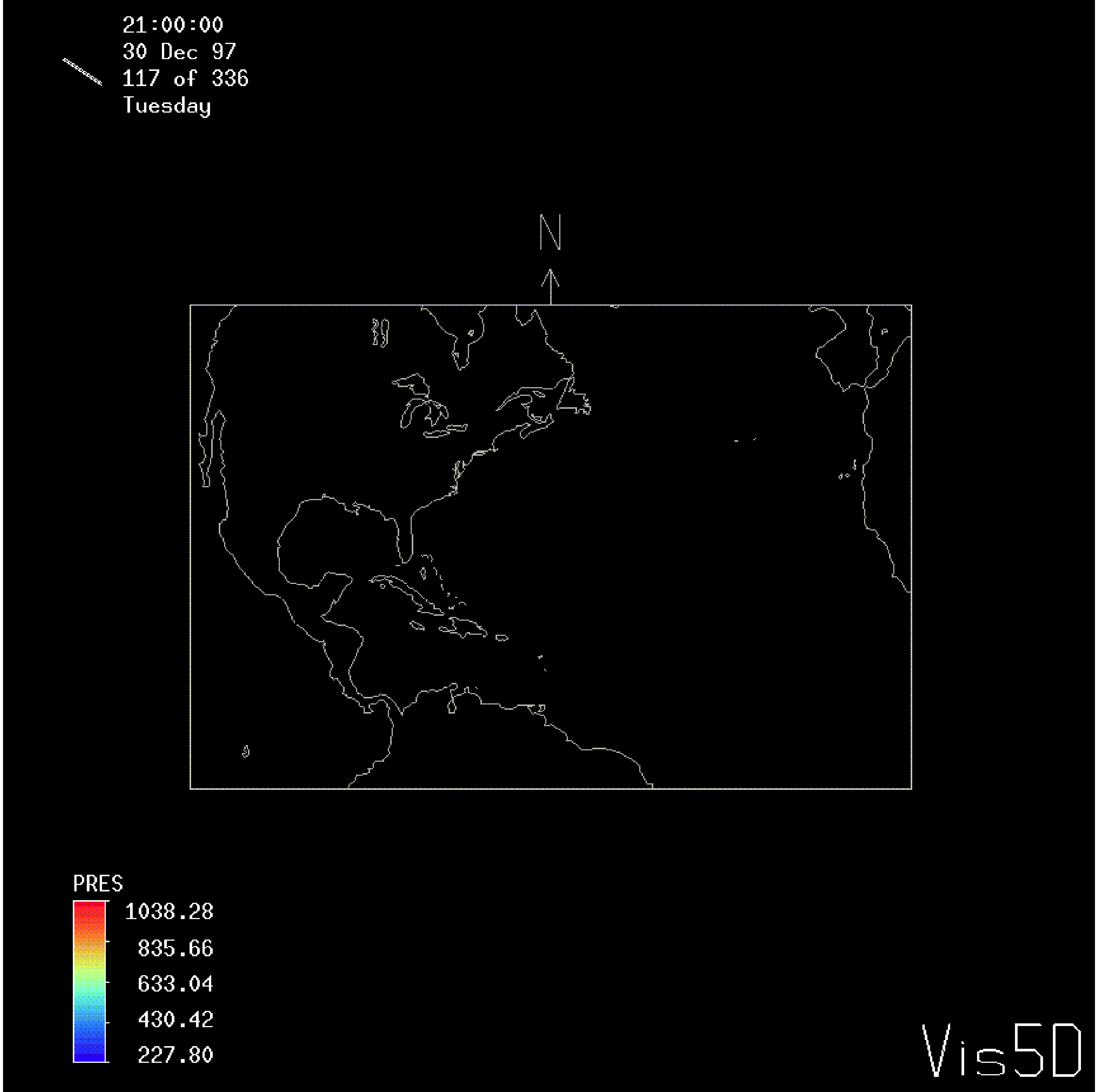
Montreal ice storm (1998): 25 mm per day times 5 days = 125 mm (-8×10^{-3} hPa per sec)

$$P = -\frac{1}{g}\int \omega \left(\frac{dr_s}{dp}\right)_{ma} dp$$

Climatology……

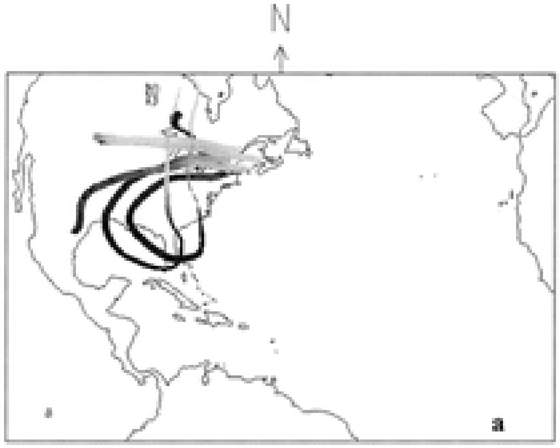


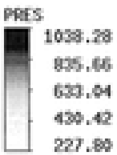
900-hPa temperatures (deg C) in parentheses

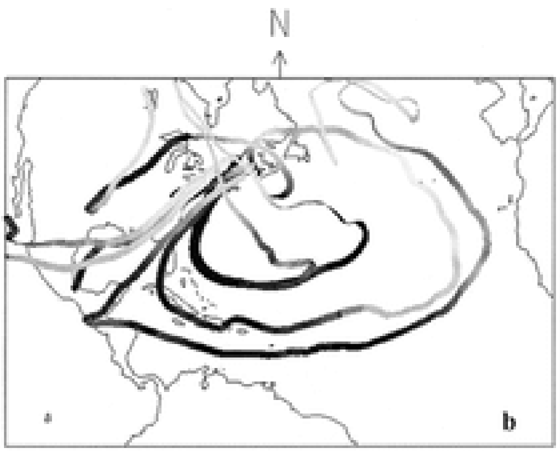


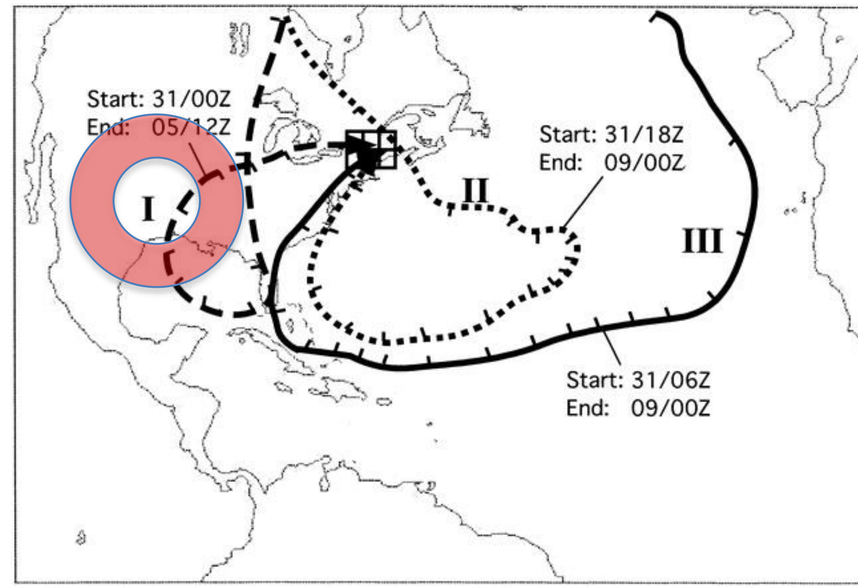
21:00:00
30 Dec 97
117 of 336
Tuesday
N
PRES
1038.28
835.66
633.04
430.42
227.80
Vis5D

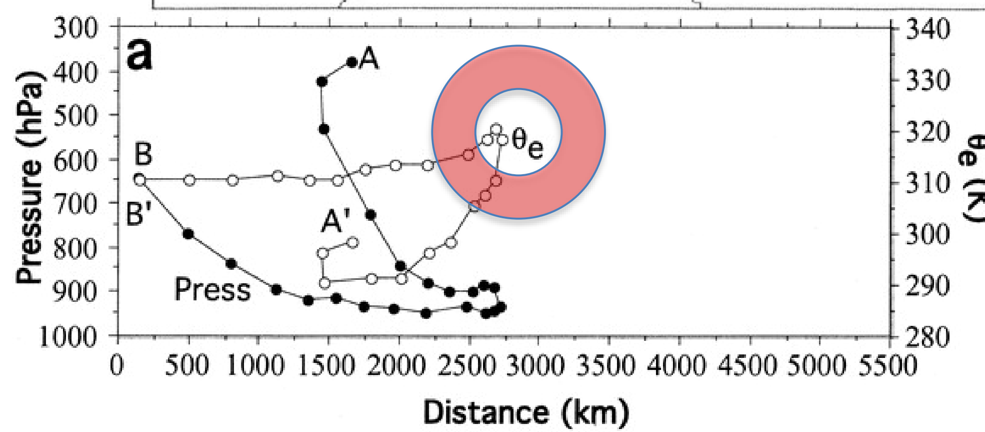
January 1998 Ice storm trajectory analysis (Roebber and Gyakum 2001)







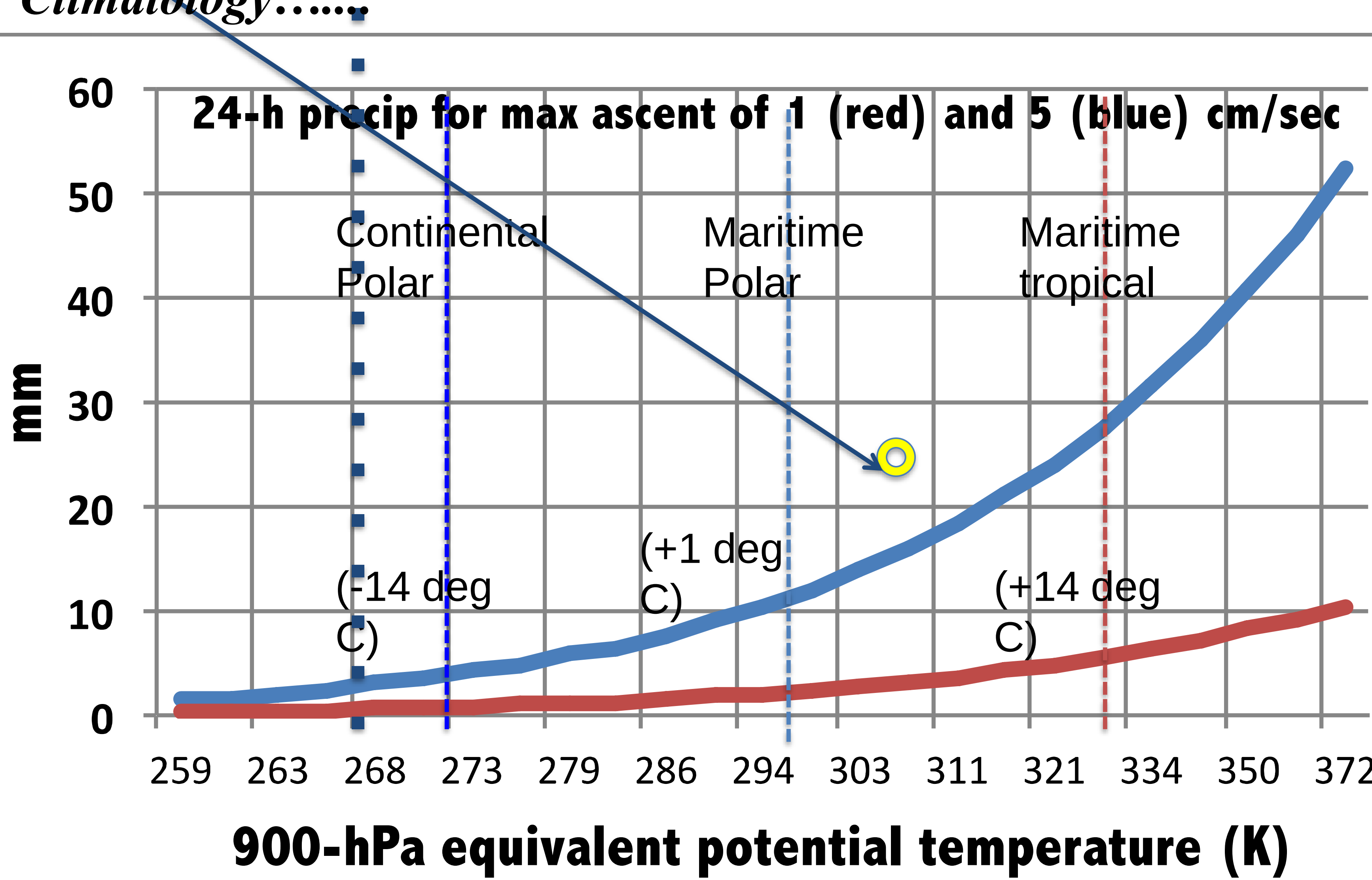




Montreal ice storm (1998): 25 mm per day times <u>*5 days*</u> = 125 mm (-8 x 10^{-3} hPa per sec)

$$P = -\frac{1}{g}\int \omega \left(\frac{dr_s}{dp}\right)_{ma} dp$$

Climatology…….



900-hPa temperatures (deg C) in parentheses

Finally….

- We find a statistically significant upward trend in 850-hPa θ_e of 1.8 K per decade in the winter.
- From our previous analysis, an increase in θ_e of 9.0 K (1.8 times 5) in 50 years time, from the extreme value of 309 K, yields 318 K
- **Given all other conditions being identical, the 1998 ice storm depth would be 165 mm in 2048, instead of 125 mm, as a consequence of climate change!**

Conclusions – Seasonal θ_e extremes for Montreal

- Montreal located between statistically significant low and high pressure anomalies to the west and east respectively. Creates anomalously strong southerly geostrophic flow (winter).
- During summer, the anomalous surface flow is southwesterly.
- Upper level flow shows a strong meridionally oriented ridge, with a negatively tilted trough (winter).
- Nearly moist adiabatic tropospheric lapse rates in all seasons, elevated dynamic tropopause, and PW (about +20 mm) values.
- Anticyclonic trajectories in all seasons: from the Gulf Stream in winter and spring; from the Gulf of Mexico in the autumn, and the continent in the summer.
- Duration/blocking regimes are a major factor in producing extreme precipitation, in the present and future climates.
- Enhancement of theta e with changing climate; provides an environment that exponentially enhances the precipitation rate.
- Extreme precipitation in Montreal is associated with air parcels being conditioned in the tropics in a huge anticyclone.
- Extreme precipitation in Montreal is associated with air parcels being conditioned in the subtropics in anticyclonic flow.

References – Thank you!

Bolton, D. 1980. The computation of equivalent potential temperature. . *Mon. Wea. Rev.*, **108**, 1046-1053.

Emanuel, K. 2008. Back to Norway: an essay. AMS Meteorological Monographs. **33**: 87-96.

Gyakum, J.R., and P.J. Roebber. 2001. The 1998 Ice Storm – analysis of a planetary-scale event. Monthly Weather Review. **129**: 2983-2997.

Gyakum, J. R., 2008: The application of Fred Sanders' teaching to current research on extreme cold-season precipitation events in the Saint Lawrence River Valley region. *Synoptic–Dynamic Meteorology and Weather Analysis and Forecasting, A Tribute to Fred Sanders.* Lance F. Bosart and Howard B. Bluestein, Eds. Amer. Meteor. Soc., 241-250**.**

Gyakum, J. R., and P. J. Roebber, 2001: The 1998 Ice Storm - analysis of a planetary-scale event. *Mon. Wea. Rev.*, **129**, 2983-2997.

Rogers, R.R., and M.K. Yau. 1989. *A Short Course in Cloud Physics Third Edition*. Burlington: Butterworth-Heinemann. Print.