North American summer heat waves and modulations from the North Atlantic simulated by an AGCM

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1) Methodology & modeling experiments

Objective: identify summertime thermal regimes conducive to warming over North America and relationships to the North Atlantic and the Atlantic Multi-decadal Variability (AMV)

Methodology: *k-means* clustering (*Michelangeli et al*, 1995) of daily maximum temperatures (Tmax) from ECHAM5 experiments (*Roeckner*, 2003), validated with NCEP2 re-analyses (not shown)

Data: ECHAM5 16 members forced by historical 1930-2013 ERSSTs (GOGA) except in the North Atlantic, where climatology (CLM) and AMV anomalies (*Ting et al*, 2009) are imposed

2) Recurrent summertime thermal regimes

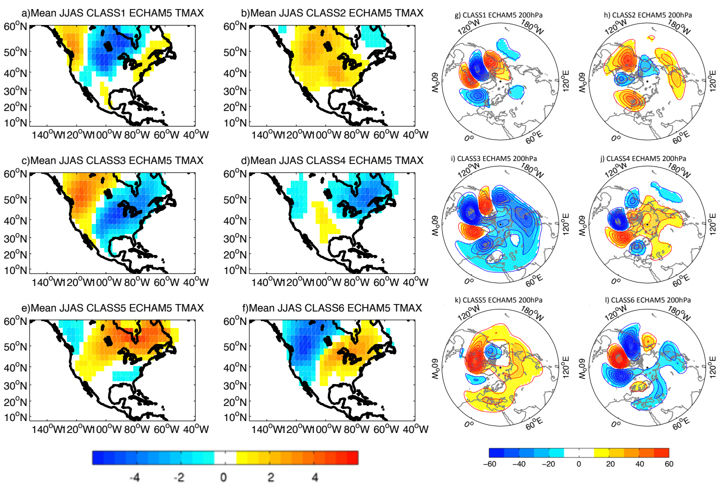

Fig.1: Mean ECHAM5 GOGA Tmax (a-f, in *Celsius*) and 200 hPa geopotential (g-l, in *m*) anomaly patterns for each thermal regimes identified over the 1930-2013 period

Maximum classifiability (not shown) for a 6-cluster partition:

2 regimes (2&5) related to broad warming with ridging anomalies in America, Europe and Asia suggest correlated heat waves

4 regimes related to westerly waves with transiting ridging and warming anomalies

3) Modulations from the North Atlantic

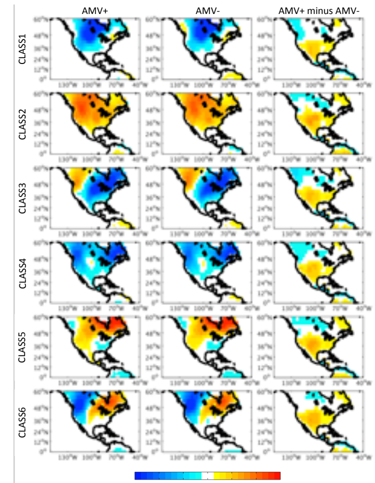

Fig.2: Similar to Fig. 1a-f but for ECHAM5 AMV+/-

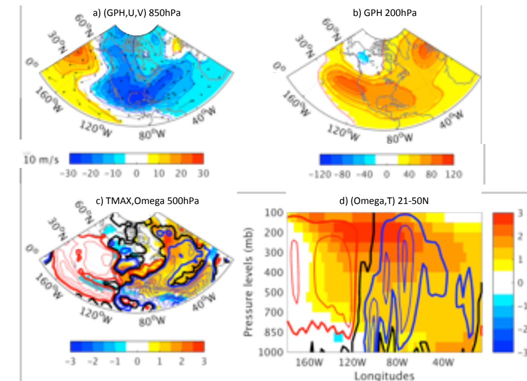

Fig.3: Differences in (a) Z850 (shadings in *m*) and winds (vectors in *m/s*), (b) Z200 (shadings, in *m*), (c) Tmax (shadings, in *Celsius*) and W500 (contours every +/-0.004 *Pa/s*), and (d) tropospheric temperatures (shading, in *Celsius*) and vertical velocities (red/blue contours starting at and every +/-0.004 *Pa/s*) between AMV+ and AMV- ECHAM5 ensemble mean during JJAS (1930-2013)

The intensity of temperature anomalies (Fig. 2) is impacted by AMV SST forcing (Fig. 3), due to upper-tropospheric warming and enhanced stability suppressing rising motion (Fig.4) leading to increased warming over the western US during positive phase of the AMV.

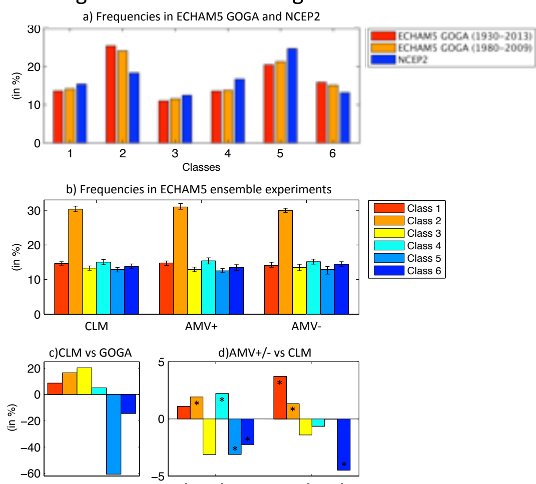

Fig.4: Percentages of Tmax regimes in NCEP2/ECHAM5 GOGA (a), CLM and AMV (b), CLM-GOGA (c) and AMV-CLM (d) differences

Observed regime frequencies from NCEP2 are well reproduced in ECHAM5 GOGA (Fig. 4a)

Removing all variability beyond the seasonal cycle in the North Atlantic (ECHAM5 CLM) leads to a sharp drop in the occurrences of regime 5 (Fig.4c) related to NE US warming

Superimposing positive/negative anomalies mimicking the AMV (ECHAM5 AMV+/-) in the North Atlantic leads to more/less warming over the west US for all regimes, but does alter regime frequencies less significantly (Fig.4b and d)

4) Conclusions

Six thermal regimes are identified over North America from ECHAM5 GOGA daily Tmax and validated with re-analyses. Two regimes of broad continental warming suggest correlated heat waves in the US, Europe and Asia. Removing all variability beyond the seasonal cycle in the North Atlantic inhibits the regime of northeast US warming. Superimposing SST anomalies mimicking AMV+/- translates in more/less warming and alters regime frequencies, but less significantly. Regime frequency changes are thus primarily controlled by Atlantic SST variability on all time-scales beyond the seasonal cycle, whereas the intensity of temperature anomalies are impacted by AMV SST forcing, due to upper-tropospheric warming and enhanced stability suppressing rising motion during positive phase of the AMV.

REFERENCES: . Michelangeli, P., R. Vautard, and B. Legras (1995) Weather regime occurence and quasi-stationarity, *J. Atmos. Sci.*, 52, 1237–1256; Roeckner, E. (2003) The atmospheric general circulation model ECHAM5. Part I: Model description, *Max Planck Institute for Meteorology Rep. 349*, 127 pp; Ting, M., Y. Kushnir, R. Seager, and C. Li (2009) Forced and internal twentieth-century SST trends in the North Atlantic. *J. Climate*, 22, 1469–1481