CLIM 796

Global Warming and Winter Extratropical Cyclones
(3-credit reading course)
Instructor: James Kinter
Spring 2023

Objective:
Review a series of papers on the topic of global warming effects on the nature and behavior of extratropical cyclones, particularly relating to Arctic amplification, changes in water vapor concentration, and changes in the stratosphere, with an emphasis on the changes in extremes. The papers listed provide sufficient background to gain a rudimentary understanding of the general role that global warming plays in changing extratropical cyclones.

Requirements:
1. Read the papers selected from the peer-reviewed literature listed below.
2. Produce a short summary of each paper (~1 page) that describes
    a. The hypothesis or problem addressed
    b. The data and methods
    c. The major results and conclusions
    d. Shortcomings, e.g., assumptions that are not applicable
3. Meet periodically with the instructor to review recent readings and discuss implications.
4. Produce a summary review (~5 pages) that describes the main take-away messages of the group of papers and synthesizes the impact of these papers on the thesis research plan.

Classes:
The class will meet three hours each week (3 credits).

Student learning outcomes:
- Gain an understanding of the secular changes in extratropical cyclones and how global warming is influencing those changes.
- Gain an understanding of the relevant physical processes inducing changes in the nature or behavior of extratropical cyclones.

Papers:
- Background on polar vortex, atmospheric blocking, and global warming impacts on thermodynamics and atmospheric circulation
    - (WEEK 1 – W1) Hakim, G. J.: *Weather, A Concise Introduction. Second Edition*. Chapters 15.3-15.6
    - (W1-2) Dacre, H. F., Hawcroft, M. K., Stringer, M. A., & Hodges, K. I. (2012). An Extratropical Cyclone Atlas: A Tool for Illustrating Cyclone Structure and Evolution Characteristics, *Bull. Amer. Meteor. Soc.*, *93*, 1497-1502. https://journals.ametsoc.org/view/journals/bams/93/10/bams-d-11-00164.1.xml
    - (W1-2) Hawcroft, M.K., Shaffrey, L.C., Hodges, K.I. and Dacre, H.F., 2012. How much Northern Hemisphere precipitation is associated with extratropical cyclones?. *Geophys. Res. Lett.*, *39*(24) https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2012GL053866

- (background) Orszag, S. A. (1970). Transform Method for the Calculation of Vector-Coupled Sums: Application to the Spectral Form of the Vorticity Equation, *Journal of Atmospheric Sciences*, *27*(6), 890-895. https://journals.ametsoc.org/view/journals/atsc/27/6/1520-0469_1970_027_0890_tmftco_2_0_co_2.xml
- (background) Bourke, W. (1972). An Efficient, One-Level, Primitive-Equation Spectral Model, *Monthly Weather Review*, *100*(9), 683-689. https://journals.ametsoc.org/view/journals/mwre/100/9/1520-0493_1972_100_0683_aeopsm_2_3_co_2.xml
- (W2) Waugh, D. W., Sobel, A. H., & Polvani, L. M. (2017). What Is the Polar Vortex and How Does It Influence Weather?, *Bull. Amer. Meteor. Soc.*, *98*, 37-44. https://journals.ametsoc.org/view/journals/bams/98/1/bams-d-15-00212.1.xml
- (W1) Lupo, Anthony R. "Atmospheric Blocking Events: A Review." *Ann. New York Acad. Sci.*, 1504, 2020, 5–24., https://doi.org/10.1111/nyas.14557.
- Kautz, Lisa-Ann, et al. "Atmospheric Blocking and Weather Extremes over the Euro-Atlantic Sector – A Review." *Wea. Climate Dyn.*, 3, 2022, 305–336., https://doi.org/10.5194/wcd-3-305-2022.
- (W3) Lejenäs, H. and Økland, H., 1983. Characteristics of Northern Hemisphere blocking as determined from a long time series of observational data. *Tellus A*, *35*(5), pp.350-362. https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1600-0870.1983.tb00210.x
- (W3) Frederiksen, J. S. (1982). A Unified Three-Dimensional Instability Theory of the Onset of Blocking and Cyclogenesis, *J. Atmos. Sci.*, 39, 969-982. https://journals.ametsoc.org/view/journals/atsc/39/5/1520-0469_1982_039_0969_autdit_2_0_co_2.xml
- (access) Nakamura, Noboru, and Clare S. Huang. "Atmospheric Blocking as a Traffic Jam in the Jet Stream." *Science*, 361, 6397, 2018, 42–47, https://doi.org/10.1126/science.aat0721.
- (W3) Woollings, T., Li, C., Drouard, M., Dunn-Sigouin, E., Elmestekawy, K. A., Hell, M., Hoskins, B., Mbengue, C., Patterson, M., and Spengler, T.: The role of Rossby waves in polar weather and climate, *Weather Climate Dyn. Discuss.* [preprint], https://doi.org/10.5194/wcd-2022-43, in review, 2022. https://wcd.copernicus.org/preprints/wcd-2022-43/wcd-2022-43.pdf
- (W3-4) Wallace, J. M., et al. "Global Warming and Winter Weather." *Science*, vol. 343, no. 6172, 2014, pp. 729–730., https://doi.org/10.1126/science.343.6172.729.
- (W3-4) IPCC Sixth Assessment Report, *Working Group 1: The Physical Science Basis*. Section 11.7

- Arctic amplification effects and changes in atmospheric blocking
  - (W5) Booth, J. F., Dunn-Sigouin, E., & Pfahl, S. (2017). The relationship between extratropical cyclone steering and blocking along the North American East coast. *Geophys. Res. Lett.*, 44, 11,976– 11,984. https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2017GL075941
  - (W5) Francis, J. A., and Vavrus, S. J. (2012), Evidence linking Arctic amplification to extreme weather in mid-latitudes, *Geophys. Res. Lett.,* 39,

    L06801, doi:10.1029/2012GL051000. https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2012GL051000
    - (W5-6) Barnes, E. A., Dunn-Sigouin, E., Masato, G., and Woollings, T. (2014), Exploring recent trends in Northern Hemisphere blocking, *Geophys. Res. Lett.*, 41, 638– 644, doi:10.1002/2013GL058745 . https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2013GL058745
    - (W5-6) Woollings, T., Barriopedro, D., Methven, J. *et al.* Blocking and its Response to Climate Change. *Curr Clim Change Rep* **4**, 287–300 (2018). https://doi.org/10.1007/s40641-018-0108-z
    - (W6) Luo, D., Chen, X., Dai, A., & Simmonds, I. (2018). Changes in Atmospheric Blocking Circulations Linked with Winter Arctic Warming: A New Perspective, *J. Climate*, *31*(18), 7661-7678. https://journals.ametsoc.org/view/journals/clim/31/18/jcli-d-18-0040.1.xml
    - (W6) Cohen, J., Zhang, X., Francis, J. *et al.* Divergent consensuses on Arctic amplification influence on midlatitude severe winter weather. *Nat. Clim. Chang.* **10**, 20–29 (2020). https://doi.org/10.1038/s41558-019-0662-y
- Changes in water vapor
    - (W7) Li M, Woollings T, Hodges K, Masato G. Extratropical cyclones in a warmer, moister climate: a recent Atlantic analogue. *Geophys. Res. Lett*. 2014;41(23):8594–601. https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2014GL062186
    - (W7) Yettella V, Kay JE. How will precipitation change in extratropical cyclones as the planet warms? Insights from a large initial condition climate model ensemble. *Climate Dyn.* 2017;49(5–6):1765–81. https://link.springer.com/content/pdf/10.1007/s00382-016-3410-2.pdf?pdf=button
    - (W7) Hawcroft M, Walsh E, Hodges K, Zappa G. Significantly increased extreme precipitation expected in Europe and North America from extratropical cyclones. *Environ. Res. Lett*. 2018;13(12). https://iopscience.iop.org/article/10.1088/1748-9326/aaed59/pdf
- Changes in stratosphere: the polar vortex and sudden stratospheric warming
    - (W8) Charney, J.G. and Drazin, P.G., 1961. Propagation of planetary-scale disturbances from the lower into the upper atmosphere. *Journal of Geophysical Research*, *66*(1), pp.83-109.
    - (W8) Matsuno, T. (1971). A Dynamical Model of the Stratospheric Sudden Warming, *Journal of Atmospheric Sciences*, *28*(8), 1479-1494. https://journals.ametsoc.org/view/journals/atsc/28/8/1520-0469_1971_028_1479_admotss_2_0_co_2.xml
    - (W8) Quiroz, R. S. (1986), The association of stratospheric warmings with tropospheric blocking, *J. Geophys. Res*., 91(D4), 5277– 5285, doi:10.1029/JD091iD04p05277. https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/JD091id04p05277
    - (W9) Baldwin, M.P. and Dunkerton, T.J., 2001. Stratospheric harbingers of anomalous weather regimes. *Science*, *294*(5542), pp.581-584.
    - (W9) Barnes, E.A., 2013. Revisiting the evidence linking Arctic amplification to extreme weather in midlatitudes. *Geophysical research letters*, *40*(17), pp.4734-4739. https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1002/grl.50880

    - (W9) Zhang, J., Tian, W., Chipperfield, M. *et al.* Persistent shift of the Arctic polar vortex towards the Eurasian continent in recent decades. *Nature Clim Change* **6**, 1094–1099 (2016). https://doi.org/10.1038/nclimate3136
    - (W9-10) Vallis, Geoffrey K., et al. "Response of the Large-Scale Structure of the Atmosphere to Global Warming." *Quart. J. Roy. Meteor. Soc.*, 141, 690, 2014, pp. 1479–1501., https://doi.org/10.1002/qj.2456.
- Changes in extremes: Bomb cyclones
    - (W10) Colucci, S. J. (1985). Explosive Cyclogenesis and Large-Scale Circulation Changes: Implications for Atmospheric Blocking, *J. Atmos. Sci.*, 42(24), 2701-2717. https://journals.ametsoc.org/view/journals/atsc/42/24/1520-0469_1985_042_2701_ecalsc_2_0_co_2.xml
    - (W10) Cohen, Judah, et al. "Linking Arctic Variability and Change with Extreme Winter Weather in the United States." *Science*, vol. 373, no. 6559, 2021, pp. 1116–1121., https://doi.org/10.1126/science.abi9167.
    - (W11) Bengtsson, Lennart, et al. "Will Extratropical Storms Intensify in a Warmer Climate?" *J. Climate*, vol. 22, no. 9, 2009, pp. 2276–2301., https://doi.org/10.1175/2008jcli2678.1.
    - (W11) Zarzycki, C. M. (2018). Projecting changes in societally impactful north-eastern U.S. snowstorms. *Geophys. Res. Lett.*, 45, 12,067–12,075. https://doi.org/10.1029/2018GL079820