Accelerated warming in the northern midlatitude summer since the 1990s

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JJA linear trend 1979-2020

NCEP/NCAR reanalysis
Extreme events tied to anomalous circumglobal wavetrains

- 2010 Russian heatwave
- 2017 heatwave, wildfire
- NAtl hurricanes
- 2020 heatwave, wildfire
- NAtl hurricanes

- Z200 1979-2020 trend
- Monthly anomalies wrt 1979-2020 climo
Multidecadal variability

Blue dots indicate local maxima from each model

42-year segments with similar Z200 trend pattern at 20-70N

NCEP/NCAR
CMIP6 hist
picont +AMV/-IPO
CMIP6 hist
CMIP6 AMIP
ERA5

Z200 (m)

Blue dots indicate local maxima from each model
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Anthropogenic trend or internal multidecadal variability?

- Large discrepancy => anthropogenic forcing plays a key role in the obs trends
- Fidelity of AMV/IPO and their teleconnections in the CMIP6 models

NCEP/NCAR: solid vertical line, ERA5: dashed, 15 models: colored lines
Eddy-mean flow interaction
with a linear planetary wave model (Branstator 1990)

- Run a 10-lev linear planetary wave model with prescribed JJA U,V,T 1979-2020 clim


\[ F = \nabla^{-2} (-v^H \cdot \nabla^H)^L \]  
(Cai and van Den Dool 1994)
Obs
Response to F
Response to F_NAtl
Response to F_NPac
Response to Trop_precip

Land-atmosphere interaction
with CESM1/CAM5 prescribed soil moisture experiments (Teng et al. 2019)

- 100-member CAM5 atm/Ind stand-alone simulation with the CESM1-LE tag
- Synoptic eddies play a crucial role in producing the circumglobal response
- Enhanced diabatic heating associated with increasing aridity in the mid-latitude, could lead to resonant amplification of waveguide Rossby waves in the boreal summer
• The 1979-2020 JJA TAS/Z200 trend **pattern is associated with** internal fluctuations of the Atlantic Multidecadal Variability (AMV) and the interdecadal Pacific Oscillation (IPO).

• The **phase shift** of AMV in the 1990s can **accelerate the warming** in the northern midlatitude summer.

• AMV and IPO in the preindustrial control runs **without external forcing** can only produce **weak** circulation and TAS anomalies.

• A linear planetary wave model indicates the **synoptic eddy-mean flow** interaction especially in the North Atlantic sector plays a more important role than tropical heating anomalies in the formation of the anomalous circumglobal wavetrain.

• The **amplitude** of the anomalous wavetrain can be **enhanced by atmosphere-land interaction** as suggested by idealized perturbed soil moisture experiments with atmosphere/land standalone configuration of CESM1.