Dynamical impact of warming patterns

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The atmosphere as a heat engine

- Hot reservoir: Tropics
- Cold reservoir: Polar regions
The Lorenz energy cycle (LEC) describes how the atmosphere maintains the general circulation by operating as a heat engine.

\[ \text{C}(P,K) \text{ determines the strength of the LEC} \]
How does this heat engine operate in a warmer climate?

warmer climate $\rightarrow$ rearrangement of reservoirs

Two controlling factors:

- changes in meridional temperature gradient
- changes in static stability

Two components:

- high-latitude surface warming
- tropical upper tropospheric warming
How does this heat engine operate in a warmer climate?

warmer climate → rearrangement of reservoirs → changes in LEC

Changes in LEC due to CO$_2$ doubling simulated by ECHAM5-T63L31/MPIOM-GR15L40. Units are W/m$^2$. 
How does this heat engine operate in a warmer climate?

warmer climate → rearrangement of reservoirs → changes in LEC

Changes in LEC due to CO₂ doubling simulated by ECHAM5-T63L31/MPIOM-GR15L40
**static stability versus meridional temperature gradient**

Investigate the two effects by separating the tropical upper-tropospheric warming (Experiment UP) from high-latitude surface warming (Experiment SFC) via nudging

- Tropical upper-tropospheric warming
  - increase in meridional temp-gradient → strengthening LEC
  - decrease in static stability → weakening LEC

- High-latitude surface warming
  - decrease in meridional temp-gradient → weakening LEC
  - increase in static stability → strengthening LEC
Temperature differences between UP / SFC and CTRL

Patterns used to force Experiment UP / SFC
weakening of LEC:
static stability dominates temp-gradient
SFC

strengthening of LEC: static stability dominates temp-gradient
The net change in LEC is essentially the sum of the responses in UP and SFC.
Baroclinicity can be measured by

- The maximum Eady growth rate
  \[ \sigma_{\text{eady}} = \frac{0.31}{N} \left| f \left| \frac{\partial u}{\partial z} \right| \right. \]

- The non-dimensional Baroclinic Parameter
  \[ BP = \frac{1}{\beta H N^2} f^2 \left| \frac{\partial u}{\partial z} \right| \]

The baroclinic pathway is more accurately described by \( BP \) than by \( \sigma_{\text{eady}} \).
Conclusion: warming up the atmosphere reduces the atmospheric heat engine

- the atmosphere cannot be heated up homogenously
- the strength of the heat engine is determined by the mean static stability
- the net effect of the mean static stability results mainly from the tropical upper tropospheric warming
- eddy kinetic energy shows corresponding changes, with the responses to the two warming patterns canceling each other to a large extent

Thanks!