The role of moisture in the energetics response to global warming

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1. The energetics response to global warming

1.1. The Lorenz Energy Cycle (LEC)

The 'energetics of the atmosphere', as described by the Lorenz Energy Cycle (LEC) (Lorenz, 1955) deals with:

- the generation **(G)** of available potential energy **(P)** (by differential heating),
- its conversion into kinetic energy **(C(P,K))** (rising of warm air and sinking of cold air),
- and its further frictional dissipation **(D)**.

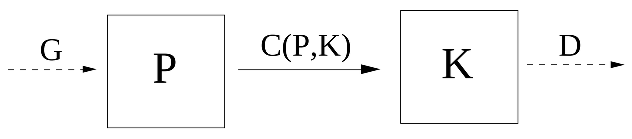


Figure 1. Two-component LEC diagram.

Zonal mean (**m**) and eddy (**e**) decomposition provide a better insight. Important steps in the cycle are:

1. Main source is the generation of Pm **(Gm)** (net low-lat heating and net high-lat cooling).
2. Conversion of **Pm** into **Pe** and into **Ke** results from baroclinic instability. →**C(Pm,Pe), C(Pe,Ke)**
3. **Ke** is converted into **Km** through eddy momentum transports. →**C(Ke,Km)**
4. Both **Ke** and **Km** are dissipated. →**Dm** & **De**
5. Conversion between **Pm** and **Km** is small and happens in both directions. →**C(Pm,Km)**

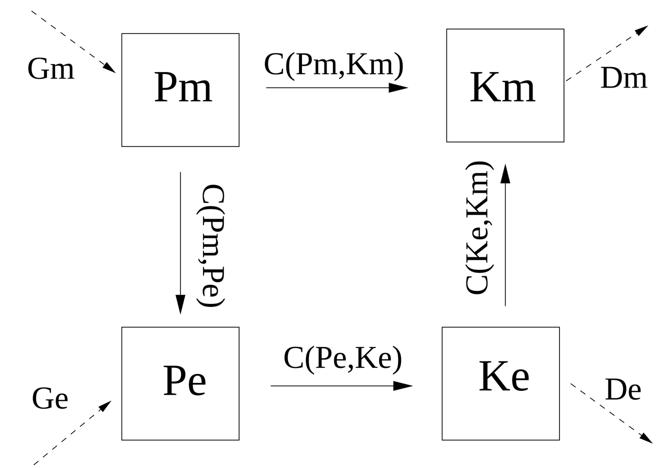


Figure 2. Four-component LEC diagram.

1.2. Results with ECHAM5/MPI-OM simulations

We use the coupled **ECHAM5/MPI-OM** model (**T63L31** resolution for the atmosphere and **GR1.5L40** for the ocean)(*):

- One **pre-industrial experiment** (50 years long, with 1xCO_2).
- One **equilibrium 2xCO_2 experiment** (50 years long).

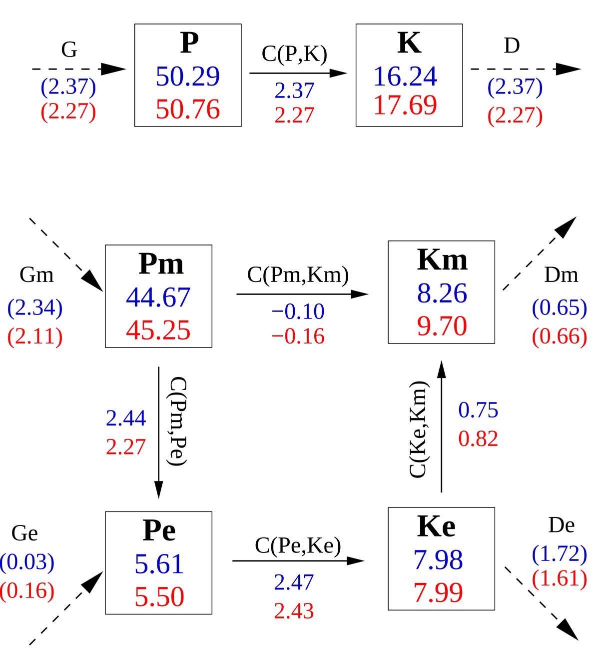
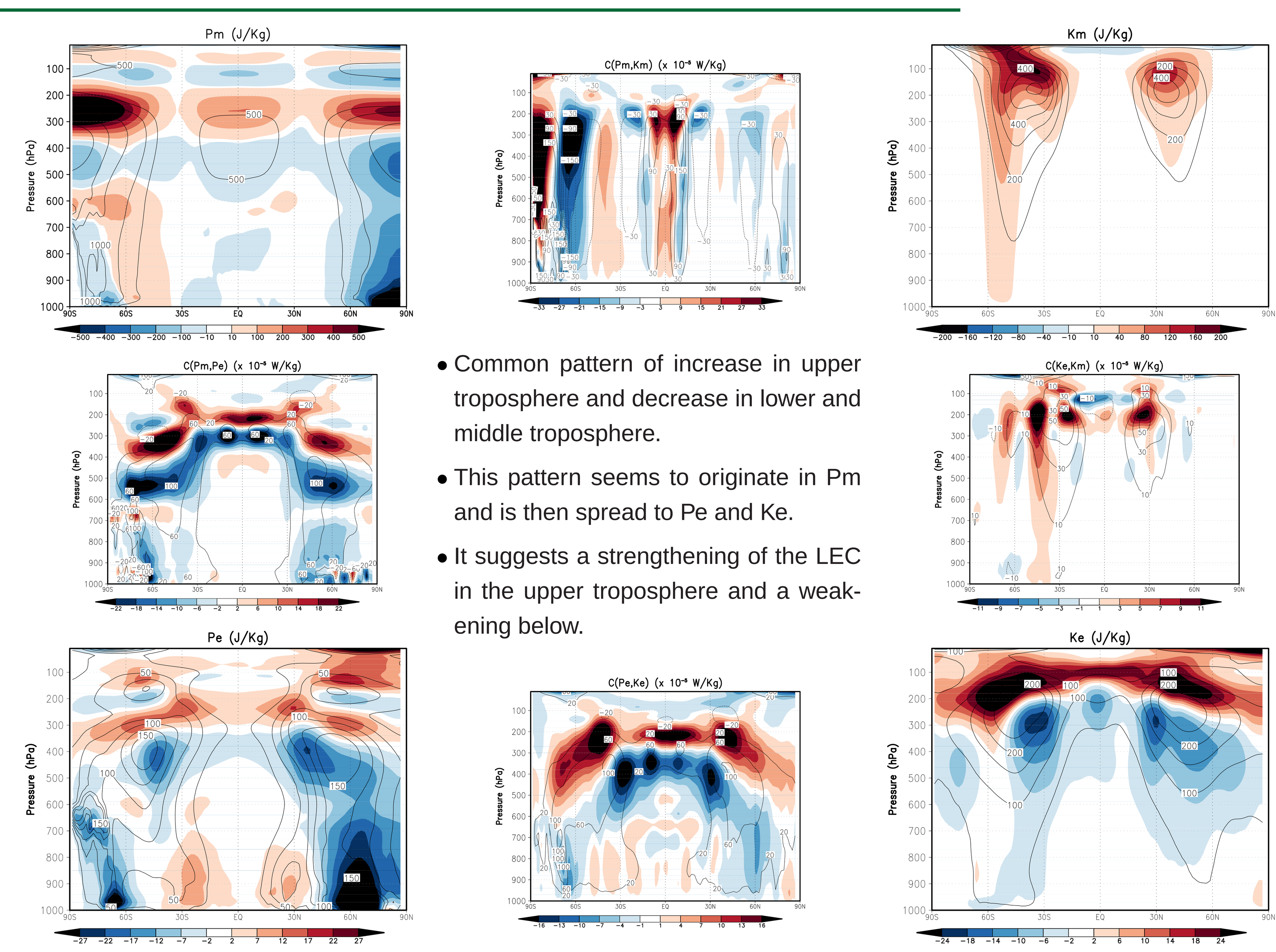


Figure 3: 2-box (above) and 4-box (below) LEC diagram with values of the 1xCO_2 control run (blue), and of the 2xCO_2 run (red). Units are 10^5 J/m^2 for reservoirs, and W/m^2 otherwise.

- The cycle is weaker (C(P,K) decreases), but K increases.
- Km increases strongly, while Ke remains unchanged.
- There is a slight decrease in the conversions C(Pm,Pe) and C(Pe,Ke), as well as in Pe, while C(Ke,Km) increases.

(*) These results are in good agreement with the previous results obtained with a lower resolution version of the same model (Hernandez-Deckers and von Storch, 2009).



- Common pattern of increase in upper troposphere and decrease in lower and middle troposphere.
- This pattern seems to originate in Pm and is then spread to Pe and Ke.
- It suggests a strengthening of the LEC in the upper troposphere and a weakening below.

Figure 4: Vertical cross-sections of reservoirs and conversion terms of the LEC in the 2xCO_2 experiment (contours), and change relative to the 1xCO_2 pre-industrial experiment (color-shaded).

2. The role of moisture (and the warming pattern)

The warming pattern of the 2xCO_2 experiment (Fig. 5) shows two regions of maximum warming:

- The upper troposphere at low latitudes.
- The lower troposphere at high latitudes,

This warming pattern implies an increase in equator-to-pole temperature difference in the upper troposphere, and a decrease in the lower troposphere, which explains the pattern of Pm-changes (Figure 4, upper left corner).

This suggests that the tropical upper-troposphere warming is causing the upper-level LEC strengthening, and therefore the strong increase in Km.

To verify this, we use the **thermal wind relationship** and two warming patterns in order to obtain the expected change of Km, based only on temperature changes (Figures 5-8).

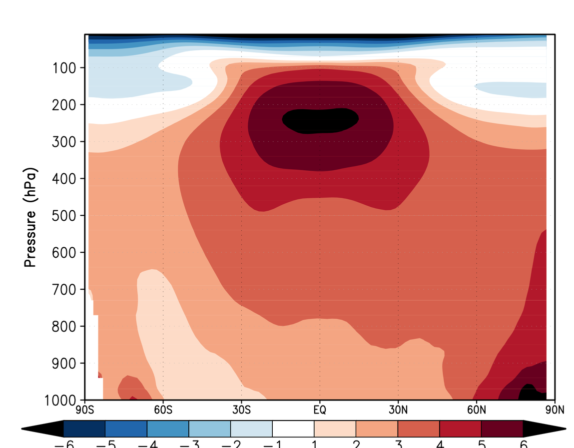


Figure 5: Zonal-mean warming pattern in the 2xCO_2 experiment relative to the 1xCO_2 pre-industrial experiment.

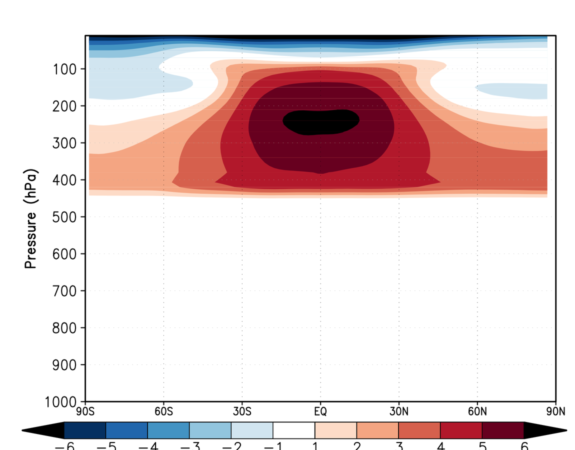


Figure 6: Same zonal-mean warming pattern as in Figure 5, but masking out the warming below 420 hPa.

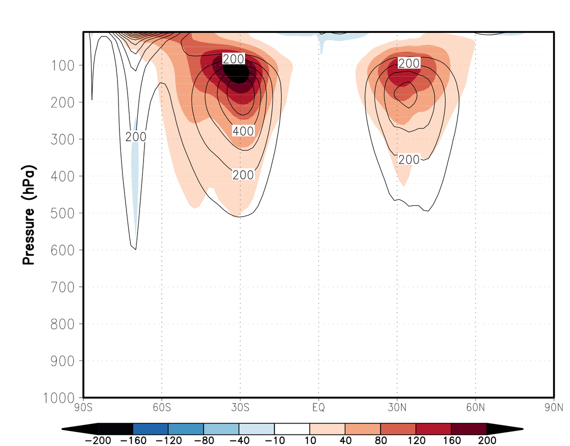


Figure 7: Vertical cross section of Km (contours) and its change (color-shaded) obtained from the thermal wind relationship and the warming pattern in Figure 5.

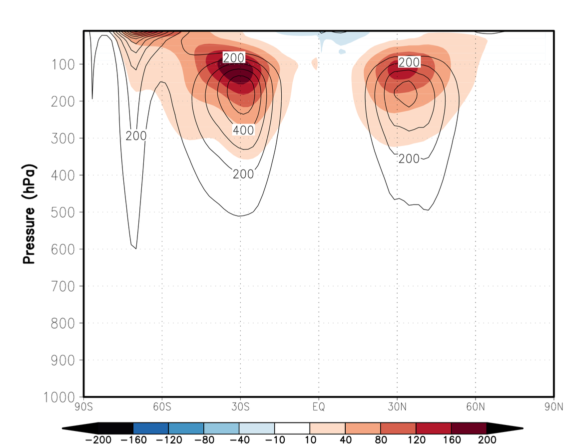


Figure 8: Vertical cross-section of Km (contours) and its change (color-shaded) obtained from the thermal wind relationship and the warming pattern in Figure 6.

Moisture effects within the tropics are the main drivers for the tropical warming (Held, 1993). Therefore, moisture is crucial for the Km-increase seen in the energetics response.

3. Conclusions and outlook

- The energetics response to doubling of CO_2 is a strengthening of the LEC in the upper troposphere and a weakening below, and is driven by the warming pattern.
- Our results show that the tropical upper-troposphere warming is the main cause for the strong Km-increase in the energetics response.
- This tropical warming is known to be related to moisture effects, so that moisture is possibly the main driver of this energetics response.
- Further research about moisture effects on the warming pattern, and about consequences of other warming patterns are currently underway.

References

Held, I. M. (1993), 'Large-Scale Dynamics and Global Warming', *Bull. Amer. Meteor. Soc.* **74**(2), 228–240.

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Lorenz, E. N. (1955), 'Available potential Energy and the Maintenance of the General Circulation', *Tellus* **7**(2), 157–167.

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