The Hydrothermal Circulation of the Atmosphere

Joakim Kjellsson, Kristofer Döös, Frédéric B. Laliberté, Jan D. Zika

Department of Meteorology, Bolin Centre for Climate Research, Stockholm University
Department of Physics, University of Toronto, ON, Canada
University of Southampton, National Oceanography Centre, United Kingdom

Contact: Joakim Kjellsson, joakim@misu.su.se

Stockholm University

- We introduce a stream function in latent heat (LH) vs. dry static energy (DSE) coordinates.
- Global atmospheric motions can be described as a unified hydrothermal circulation.
- The hydrothermal circulation includes two hemisphere-wide meridional cells as well as the zonally oriented Walker Circulation.
- Total strength: 418 Sv. The meridional overturning explain less than 70% and zonally oriented flows (e.g. Walker Circulation) explain 30%.

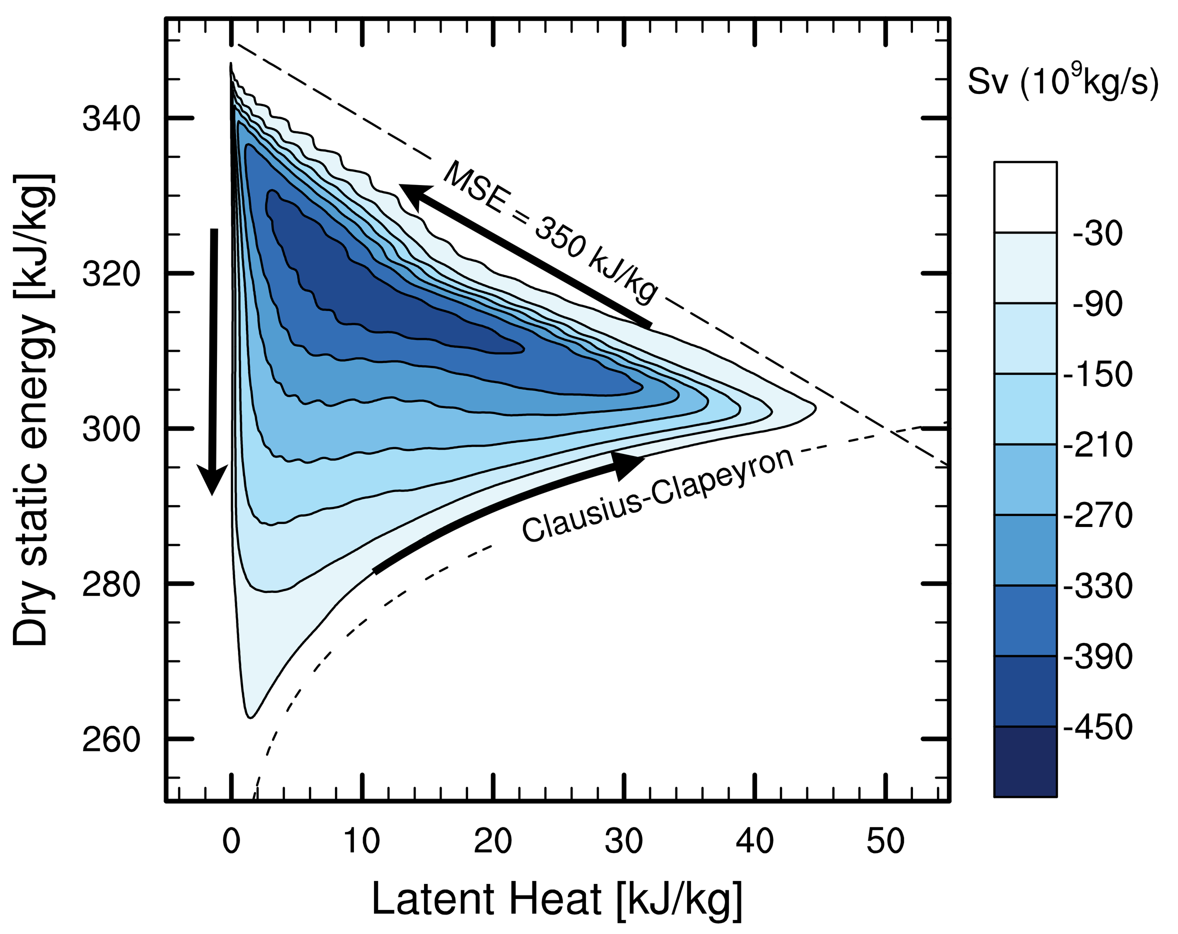

Fig 1: *Global hydrothermal stream function, ψ(l,s), in units Sv = 10^9 kg s^{-1}, an iso-line of 350 kJ/kg moist static energy (dashed) and the Clausius-Clapeyron curve for saturated surface air (double dashed). Horizontal axis is latent heat and vertical axis is dry static energy, both in units kJ kg^{-1}. Amplitude of ψ(l,s) is -418 Sv.*

The hydrothermal circulation has three branches:

1. A moist convective branch where LH is converted into DSE along moist adiabats. MSE is approximately conserved.
2. A subsiding branch where very dry air near LH=0 loses DSE due to radiative cooling.
3. A return branch where dry, cold air is moistened and heated in the atmospheric boundary-layer. It is bounded by the Clausius-Clapeyron relationship.

We use 6-hourly temperature, specific humidity, surface pressure, and horizontal winds on model levels from the ERA-Interim dataset in 1979-1989. We calculate vertical velocity, geopotential, and dry static energy (DSE), latent heat (LH), and moist static energy (MSE).

$$
\begin{aligned}
s &= c_pT + gz \\
l &= L_vq \\
h &= l + s
\end{aligned}
$$

We then calculate the hydrothermal stream function (eq. 1) as an atmospheric equivalent to the thermohaline stream function (Döös *et al.* 2012, Zika *et al.* 2012). The result is a single hydrothermal circulation.

$$\psi(l,s) = \frac{1}{t_1 - t_0}\int_{t_0}^{t_1}\iint_{A_s(l,s)}\frac{1}{g}\vec{v}\cdot d\vec{A}\;dt,$$

The hydrothermal circulation describes mass fluxes across iso-surfaces of LH and DSE. ψ(l,s) is the total mass flux across the DSE surface *s* at LH less than *l*.

We select the stream layer 100 - 400 Sv and project it onto the time-averaged distributions of LH and DSE in the ERA-Interim data. We find a meridional overturning similar to that derived using residual-mean or isentropic-mean frameworks (cf. Karoly *et al.* 1997). We also find zonal asymmetries in the tropics, where the rising and subsiding branches are part of the Walker Circulation.

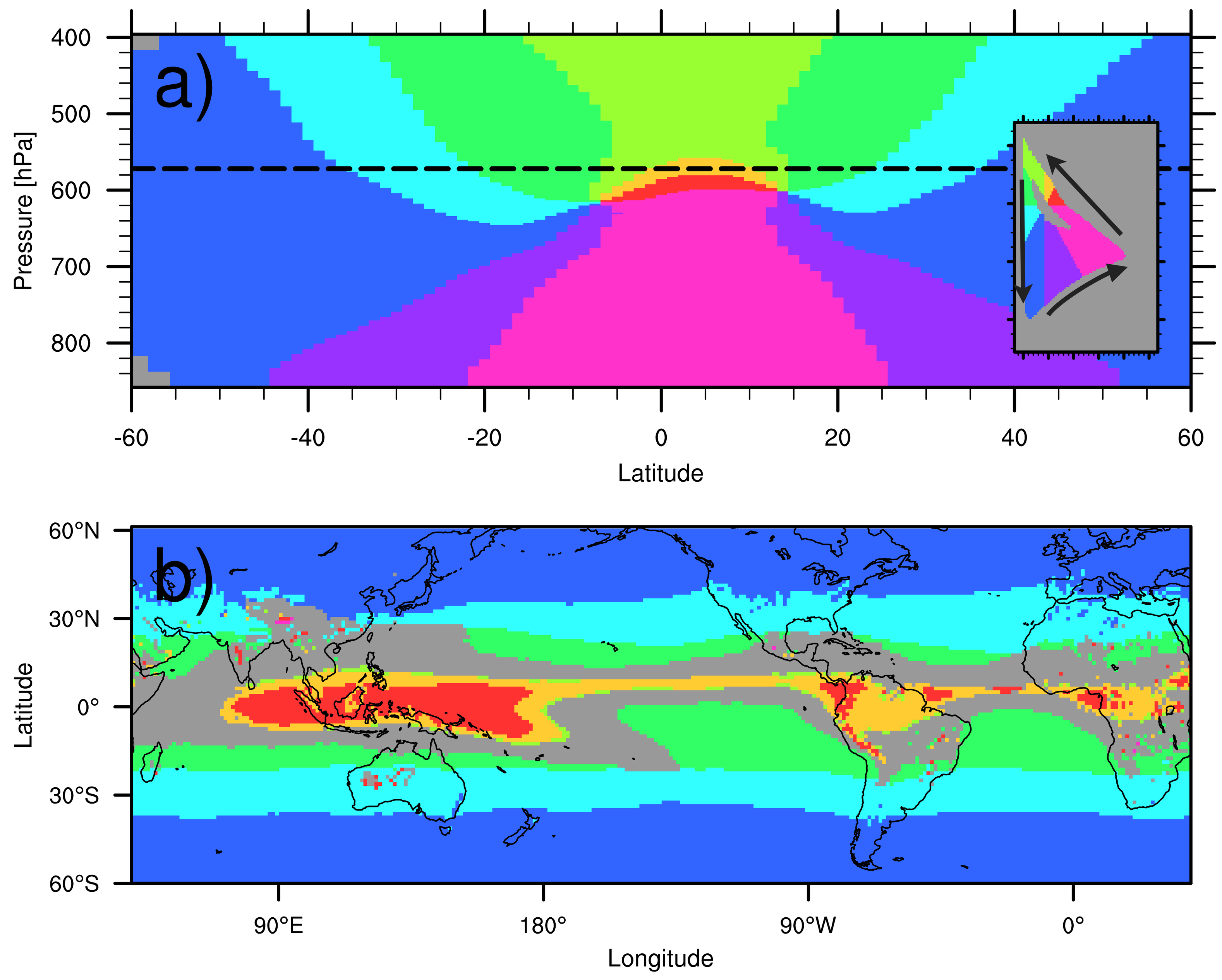

Fig 2: *The hydrothermal circulation between -100 and -400 Sv subdivided into sections and coloured individually (inlay in a), and projected onto the time-averaged LH and DSE. Colours indicate high LH (purple), low LH (light blue), high DSE (green) and low DSE (blue). Air masses outside the stream layer are shaded gray. a) The zonal mean shows a meridional overturning circulation where air ascends in the tropics, moves poleward while slowly sinking, and then returns to the tropical boundary layer. b) shows the mid-troposphere (≈570 hPa) with large zonal asymmetries in both the rising and sinking branches, known as the Walker Circulation.*

References:

Döös, K., Nilsson, J., Nycander, J., Brodeau, L. & Ballarotta, M. The world ocean Thermohaline Circulation. *J. Phys. Oceanogr.* **42**, 1445–1460 (2012).

Karoly, D. J., McIntosh, P. C., Berrisford, P., McDougall, T. J. & Hirst, A. C. Similarities of the Deacon Cell in the Southern Ocean and the Ferrel Cells in the atmosphere. *Q. J. R. Meteorol. Soc.* **123**, 519–526 (1997).

Zika, J., England, M. & Sijp, W. The ocean circulation in Thermohaline coordinates. *J. Phys. Oceanogr.* **42**, 708-724 (2012).