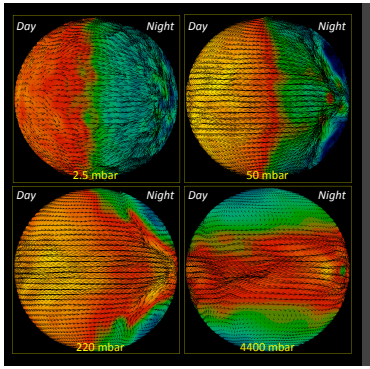


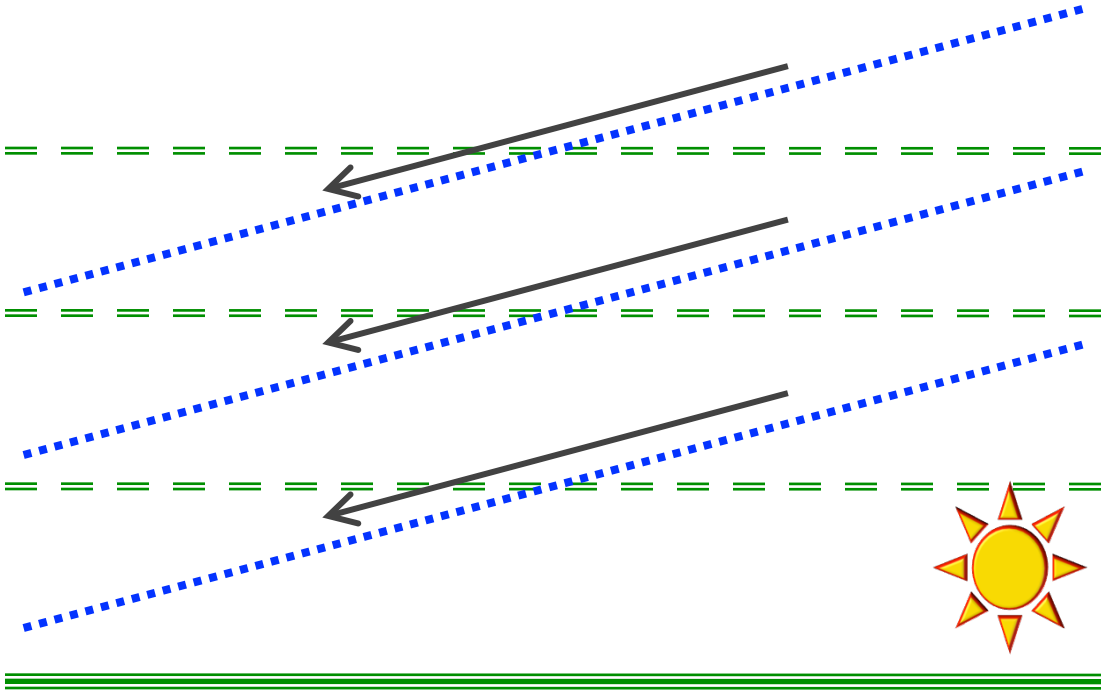
The Role of Drag in the Energetics of Hot Jupiter Atmospheres

Emily Rauscher

Sagan Fellow, University of Arizona, LPL

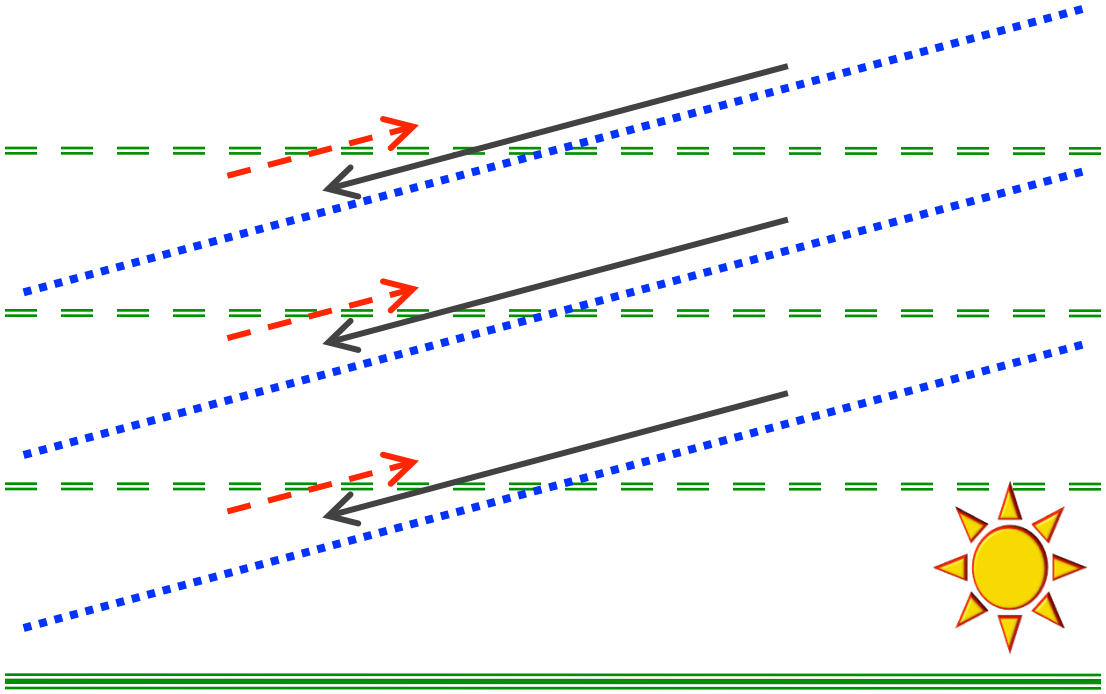
(Rauscher & Menou, proto-submitted)

A cartoon atmospheric model



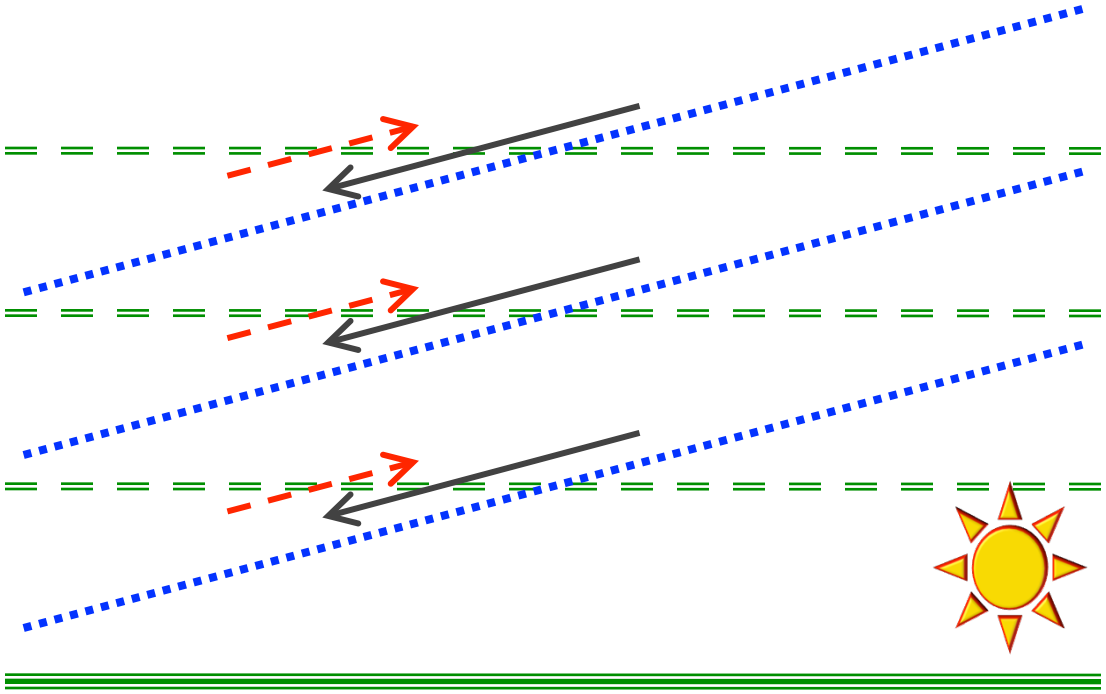
Differential heating drives the circulation.

A cartoon atmospheric model



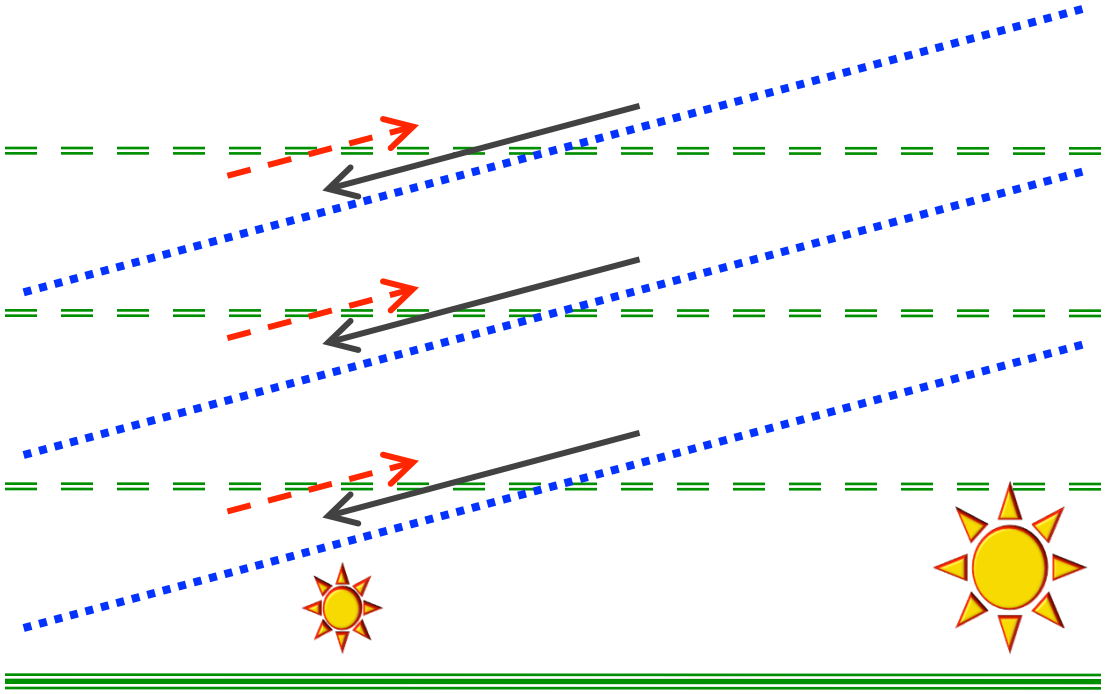
There may be important sources of drag …
(Goodman 2009, Dobbs-Dixon et al. 2010, Li & Goodman 2010, Perna et al. 2010, Rauscher & Menou 2010)

A cartoon atmospheric model



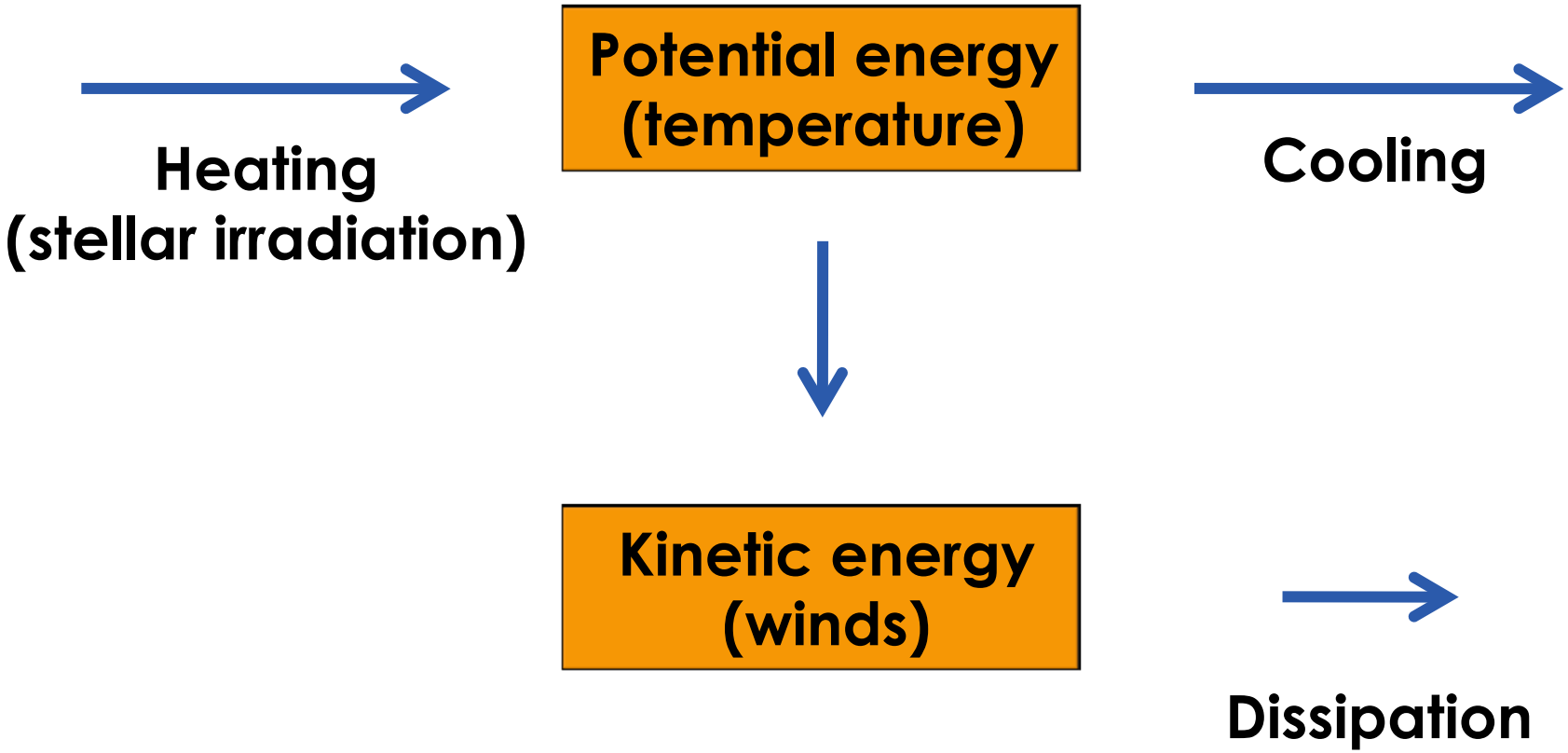
which will decrease the speed of the winds,

A cartoon atmospheric model



as well as provide an additional source of **heating**

Atmospheric Energetics



Available Potential Energy

- Original: Lorenz (1955) – component of potential energy available for direct conversion into kinetic energy

Available Potential Energy

- Original: Lorenz (1955) – component of potential energy available for direct conversion into kinetic energy
- Global: Pearce (1978) – created through differential heating

$$d\hat{a}/dt = d\hat{e}_{tot}/dt - d\hat{u}/dt = -\hat{c} - \widehat{q^*(T_r/T)^*}$$

Available Potential Energy

- Original: Lorenz (1955) – component of potential energy available for direct conversion into kinetic energy
- Global: Pearce (1978) – created through differential heating

$$d\hat{a}/dt = d\hat{e}_{tot}/dt - d\hat{u}/dt = -\hat{c} - \widehat{q^*(T_r/T)^*}$$

- Local: Marquet (1991) – local terms for generation and conversion

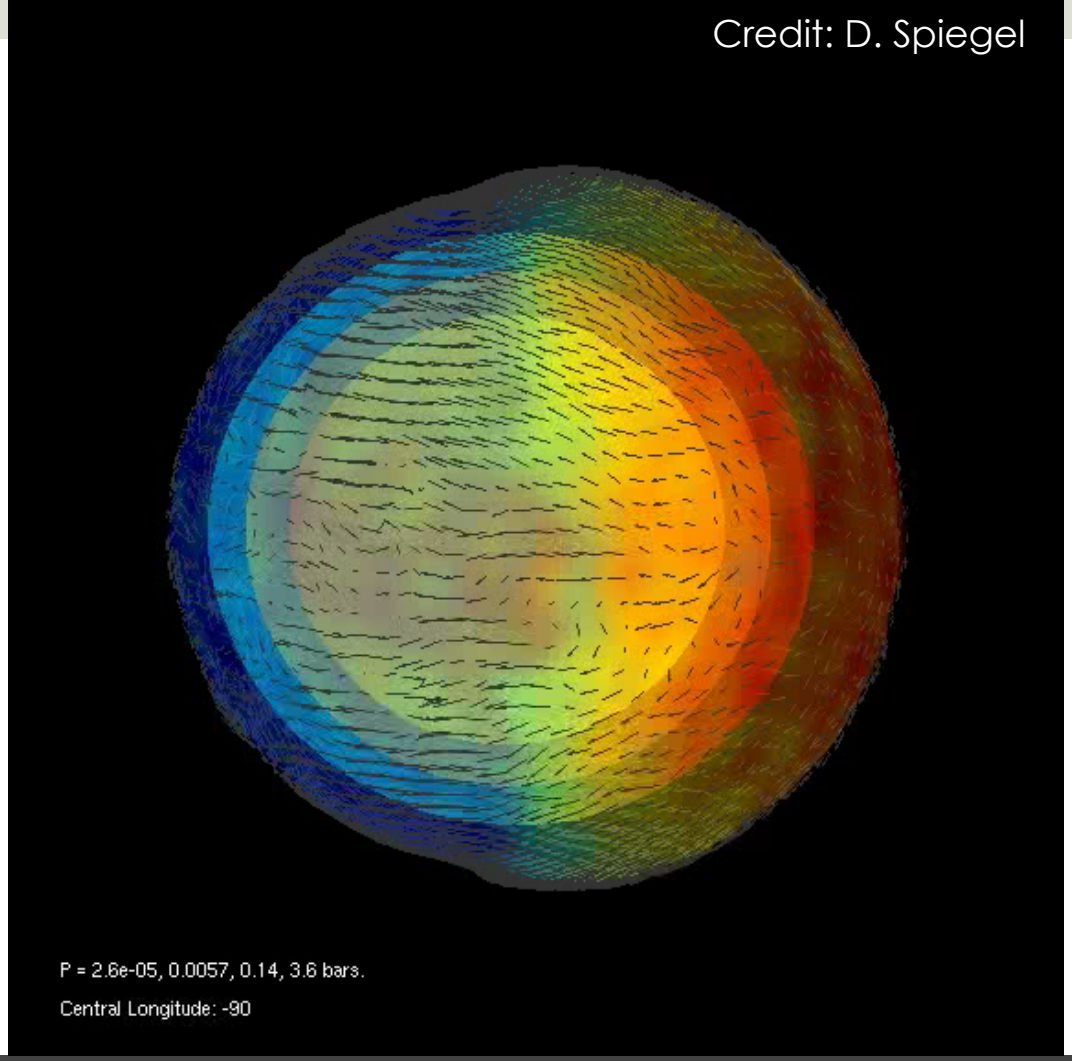
Local energy cycle

$$\frac{Du}{Dt} = \left[\frac{T_r}{T}\right](q_{\rm rad} + q_f)$$

$$\frac{Da}{Dt} = \left[1 - \frac{T_r}{T}\right](q_{\rm rad} + q_f) + \frac{1}{\rho}(\vec{v}\cdot\nabla P) - wg + \frac{1}{\rho}\frac{\partial P}{\partial t}$$

$$\frac{De_K}{Dt} = -\frac{1}{\rho}(\vec{v}\cdot\nabla P) - \mathcal{D}$$

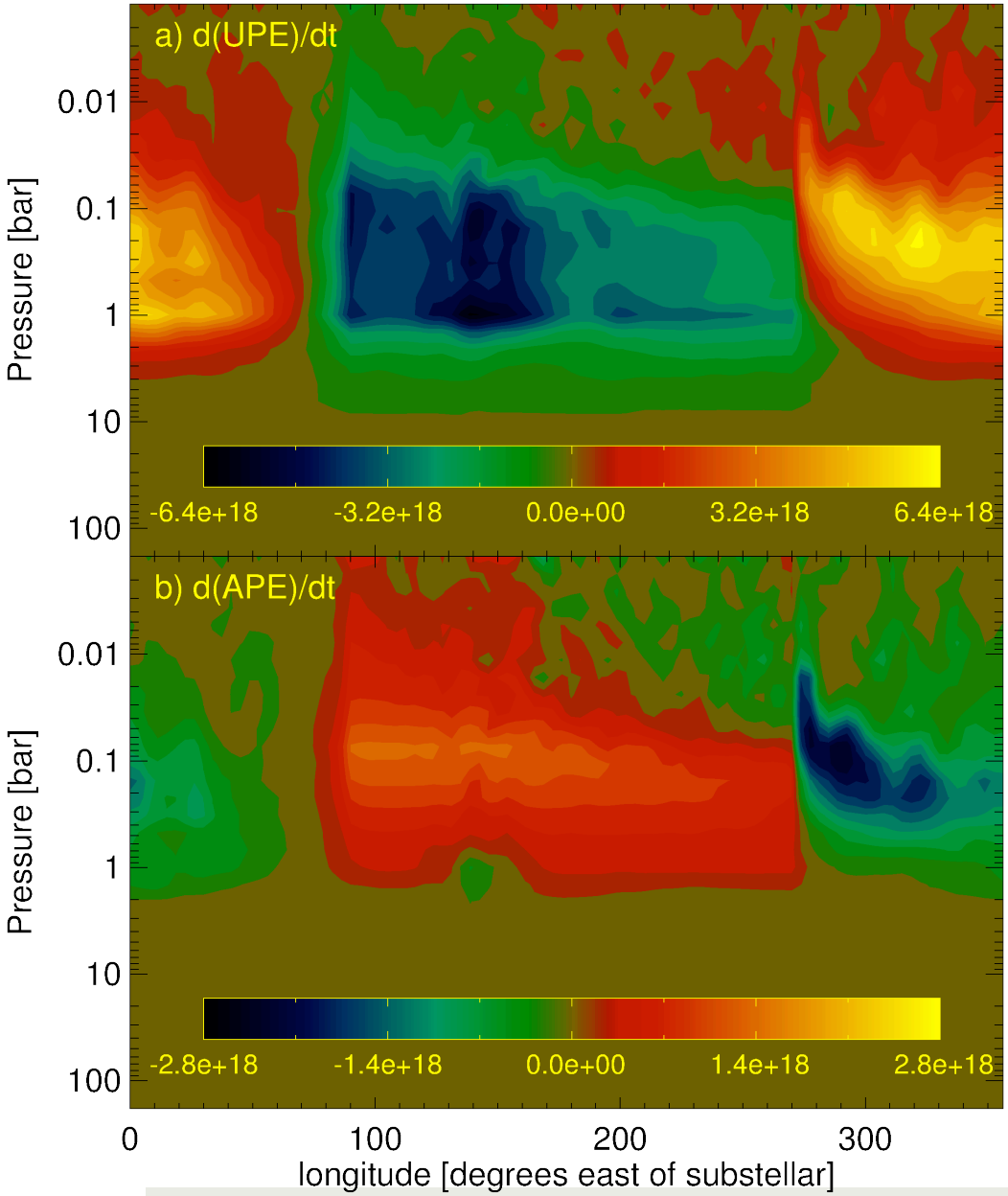
$$\frac{De_G}{Dt} = wg$$



Numerical models

Rauscher & Menou (2010); Perna, Menou, & Rauscher (2010)

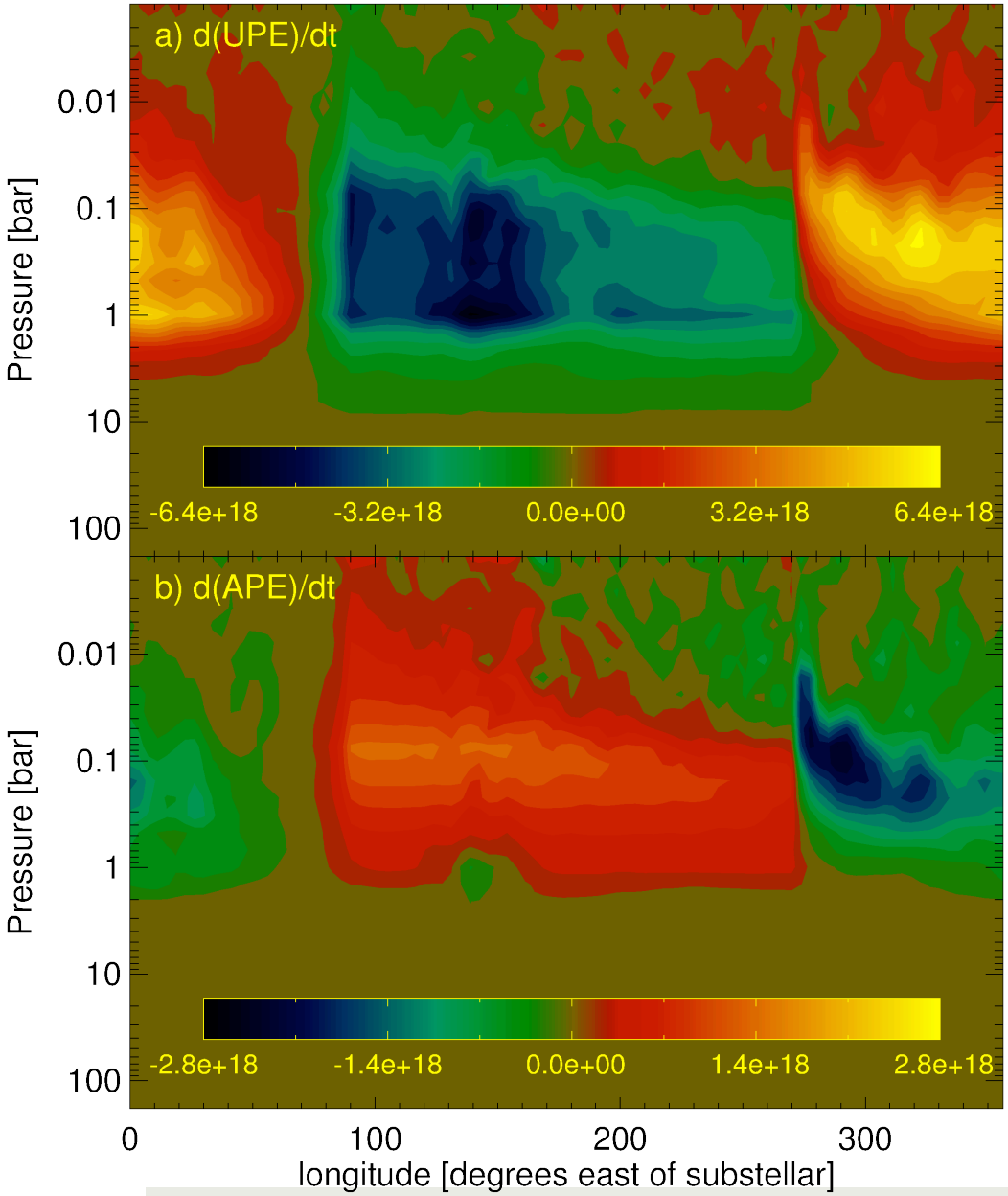
Radiative APE generation



$$\frac{Da}{Dt} = \left[1 - \frac{T_r}{T}\right](q_{\mathrm{rad}} + \cancel{q_\phi}) +$$

Model without drag (RM10)

Radiative APE generation



$$\frac{Da}{Dt} = \left[1 - \frac{T_r}{T}\right](q_{\mathrm{rad}} + \cancel{q_\phi}) +$$

Model without drag (RM10)

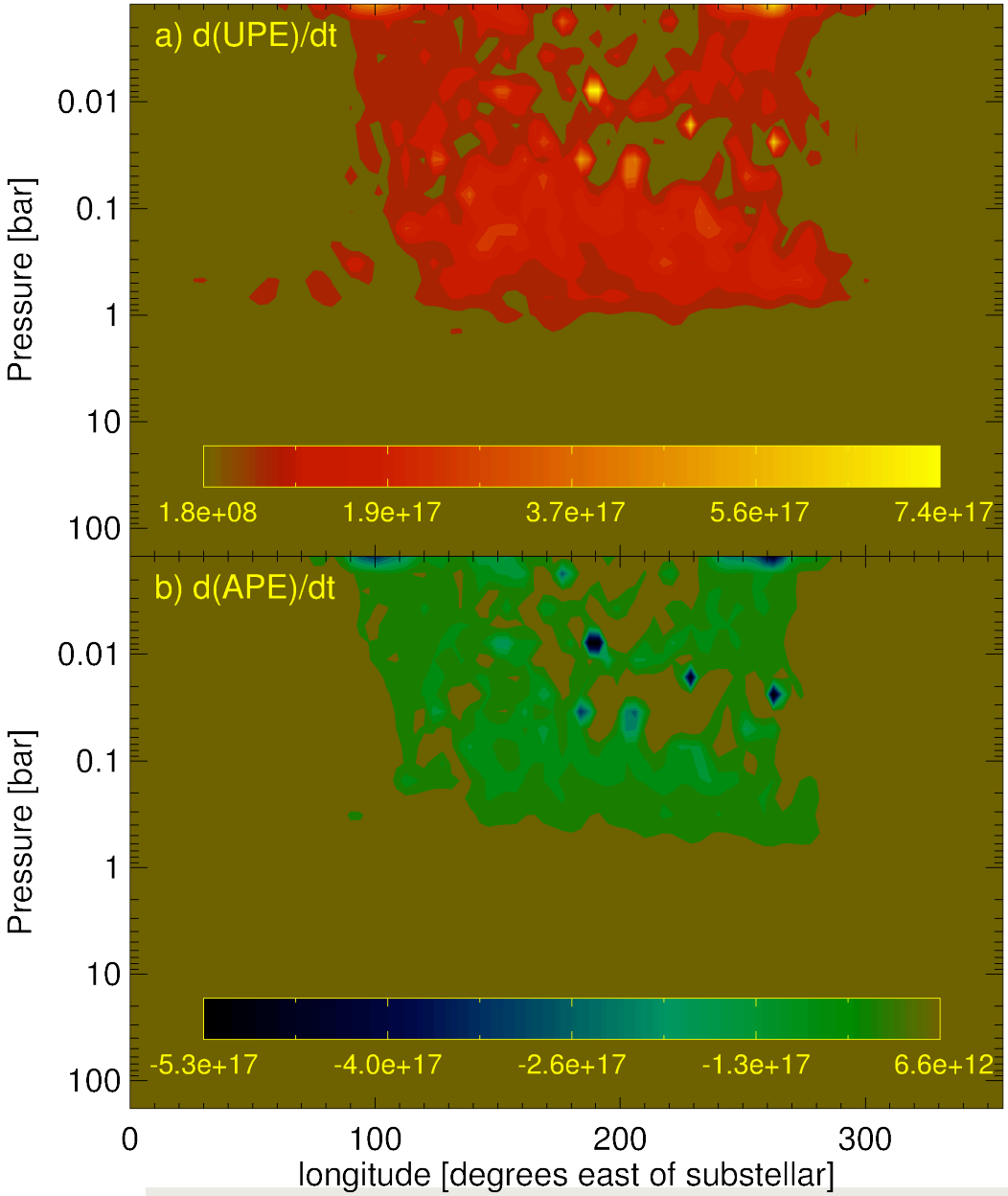
- APE is generated on the night side of the planet

$$\frac{1}{T_r} \equiv \int_{atm} \frac{1}{T} \frac{dm}{\mathcal{M}}$$

T_r = 1800 K
$(T_r/T) > 1$ for P < 10 bar

- This is not strictly the case, due to the advected temperature structure

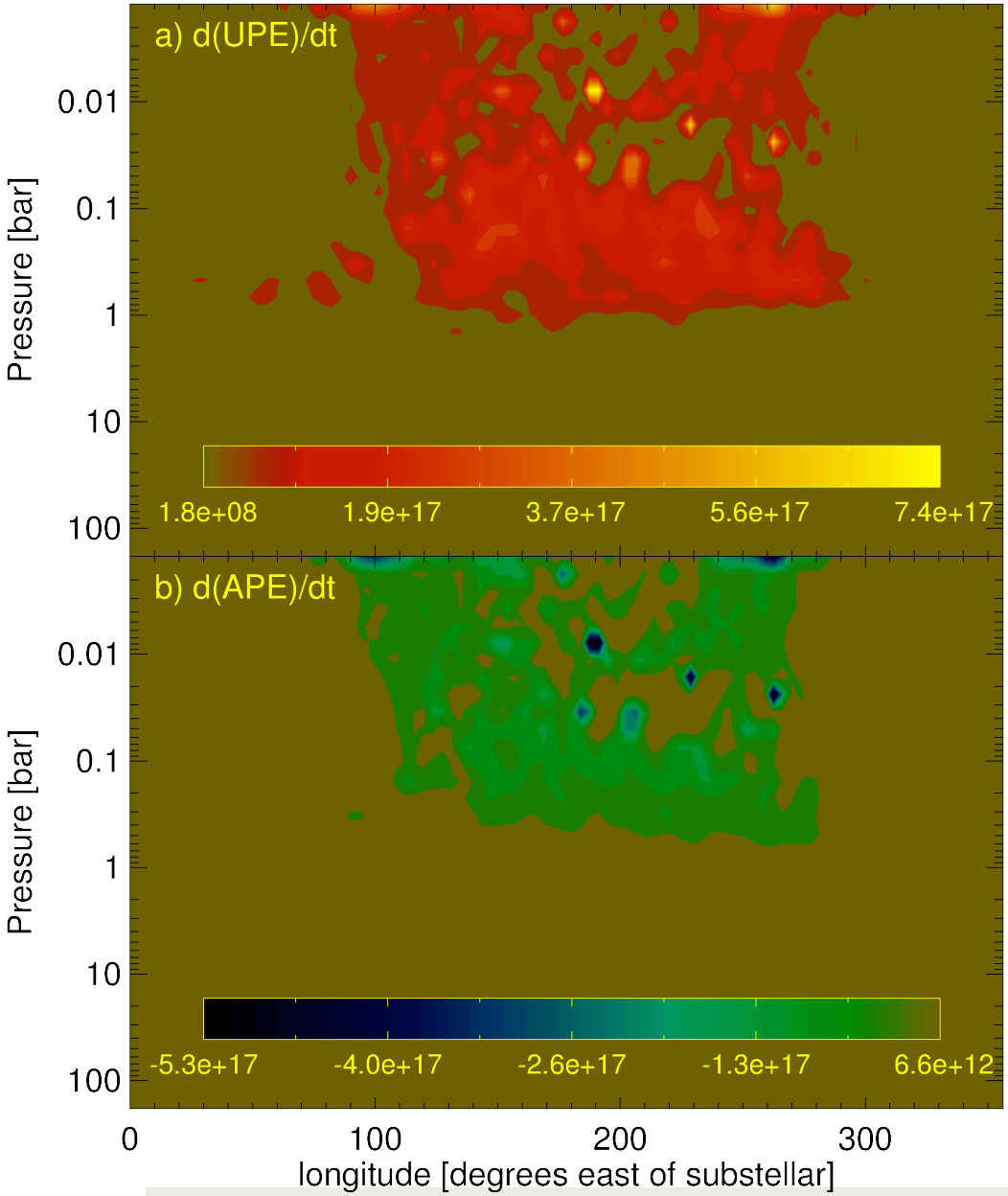
Frictional APE generation



$$\frac{Da}{Dt} = \left[1 - \frac{T_r}{T}\right](\mathcal{D} + q_f) + q_f$$

Model with strong drag (PMR10c)

Frictional APE generation



$$\frac{Da}{Dt} = \left[1 - \frac{T_r}{T}\right](Q_{rad} + q_f) + \mathcal{D} = q_f$$

Model with strong drag (PMR10c)

- Most of the kinetic energy is on the night side
- APE is lost on the night side of the planet ($q_f > 0$ always)

Global energetics

	RM10[a]	PMRa[b]	PMRb[b]	PMRc[b]
Radiative heating, q_{rad} ($\times 10^{19}$ W)	160, 150, 180	390	430	610
Generation of UPE ($\times 10^{19}$ W)	-39, -65, -20	-19	-45	-5.0
Generation of APE ($\times 10^{19}$ W)	200, 210, 200	410	470	620
Drag dissipation, $\mathcal{D}$ ($\times 10^{19}$ W)	0	3.8	34	170
Relative to q_{rad}:	0	1%	8%	28%
Missing UPE gen. ($\times 10^{19}$ W)	0	7.3	68	340
Relative to q_{rad} UPE gen.:	0	38%	150%	6800%
Missing APE gen. ($\times 10^{19}$ W)	0	-3.4	-34	-170
Relative to q_{rad} APE gen.:	0	1%	7%	27%

More drag →

Caveats!

- We assume: kinetic energy dissipated is **locally** converted into heating

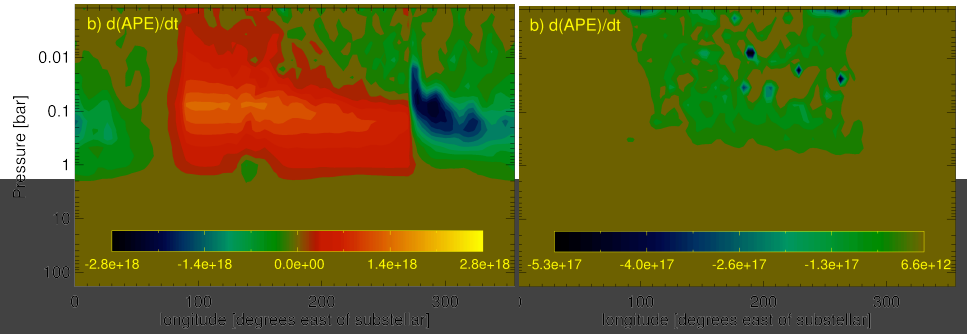
Caveats!

- We assume: kinetic energy dissipated is **locally** converted into heating
- The generation of APE depends on the strength and **spatial pattern** of the drag; for more localized drag, weaker strengths could still significantly alter the circulation.

Caveats!

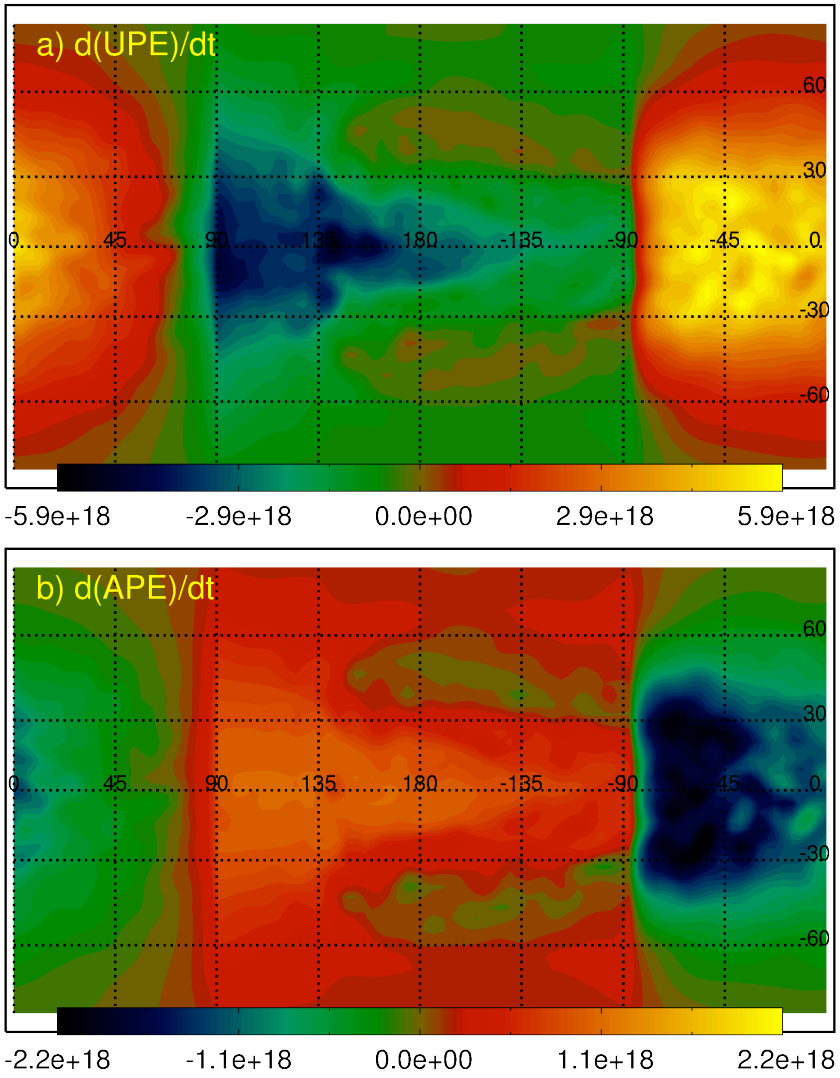
- We assume: kinetic energy dissipated is **locally** converted into heating
- The generation of APE depends on the strength and **spatial pattern** of the drag; for more localized drag, weaker strengths could still significantly alter the circulation.
- We are neglecting any **time-variability** (which will definitely be important for eccentric planets)

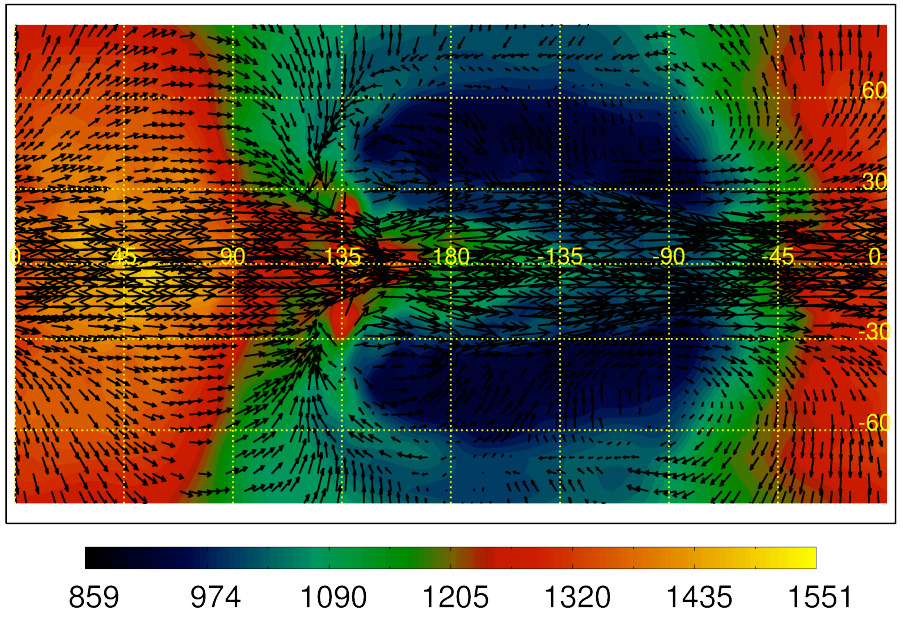
Summary



- APE is produced by differential heating and is converted to kinetic energy (winds).
- An energetic analysis of the atmosphere can determine the potential influence of heating sources on the circulation.
- If the frictional heating could have a significant influence on the APE generation, then it should be explicitly included in numerical models to determine *how* it affects the circulation.

RM10: horizontal slice at 150 mbar





PMRc: horizontal slice at 150 mbar