The Thermodynamic Control of Tropical Rainfall

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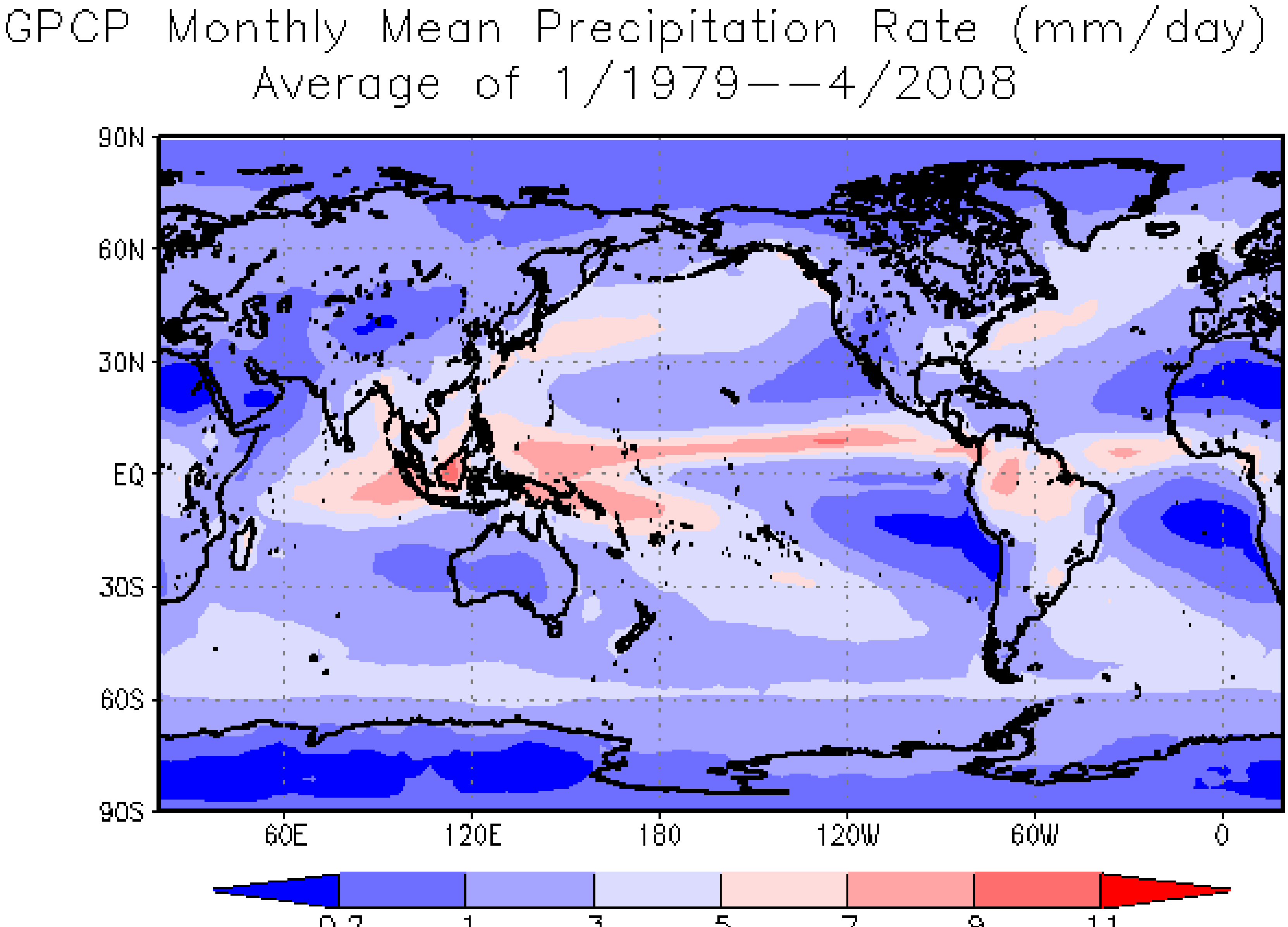
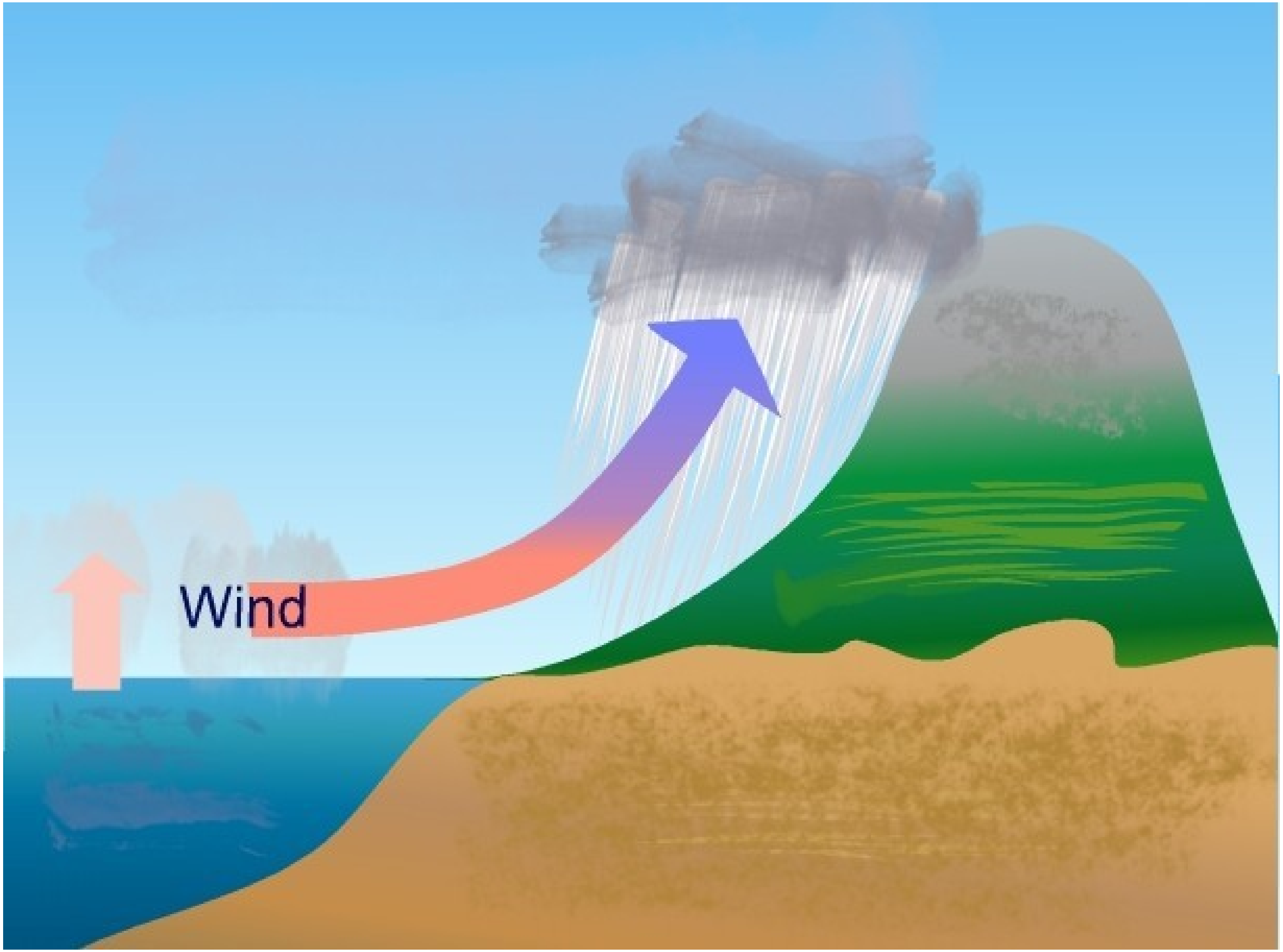
Ivica Crljenica, PMF-FO Split
25.V '09., SWAP

Precipitation

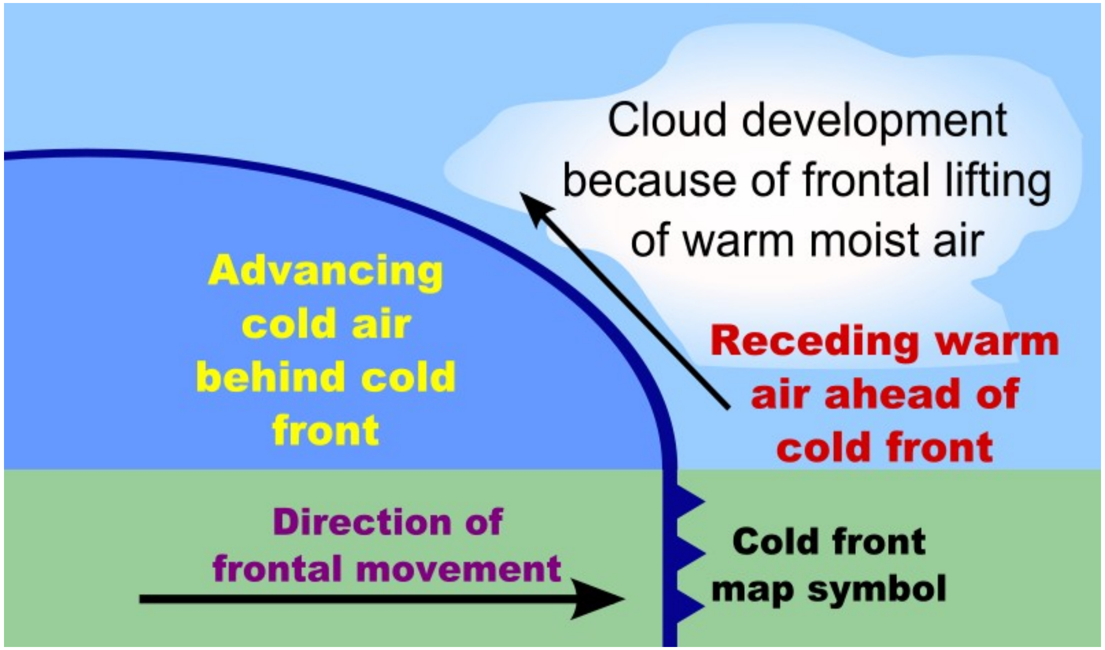


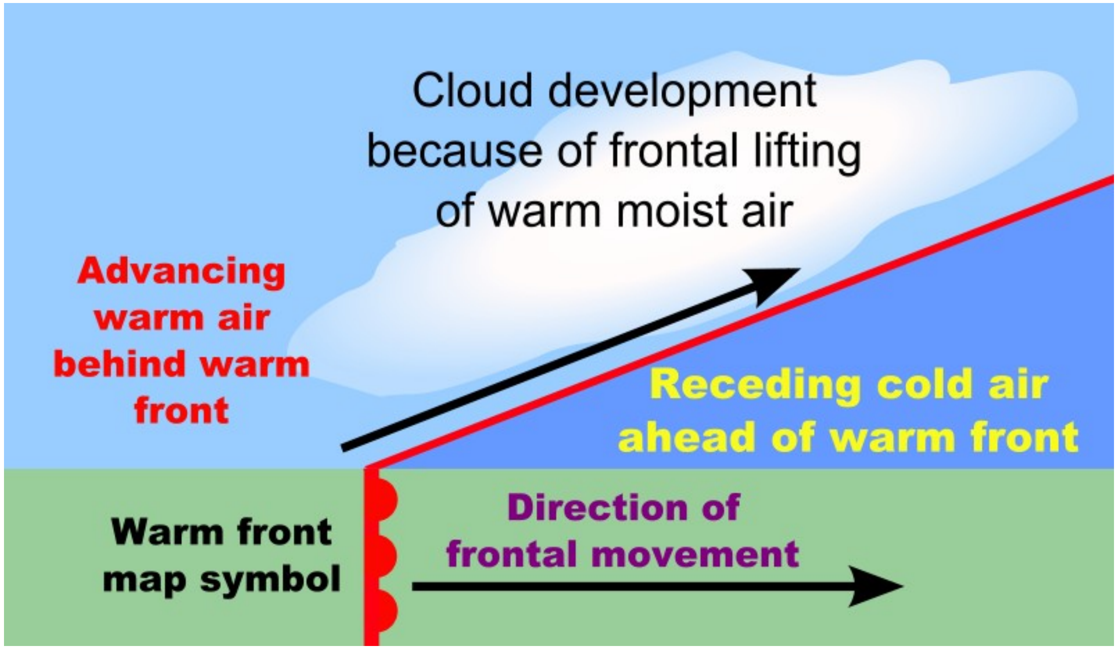
Global Precipitation Climatology Project

Orographic forcing

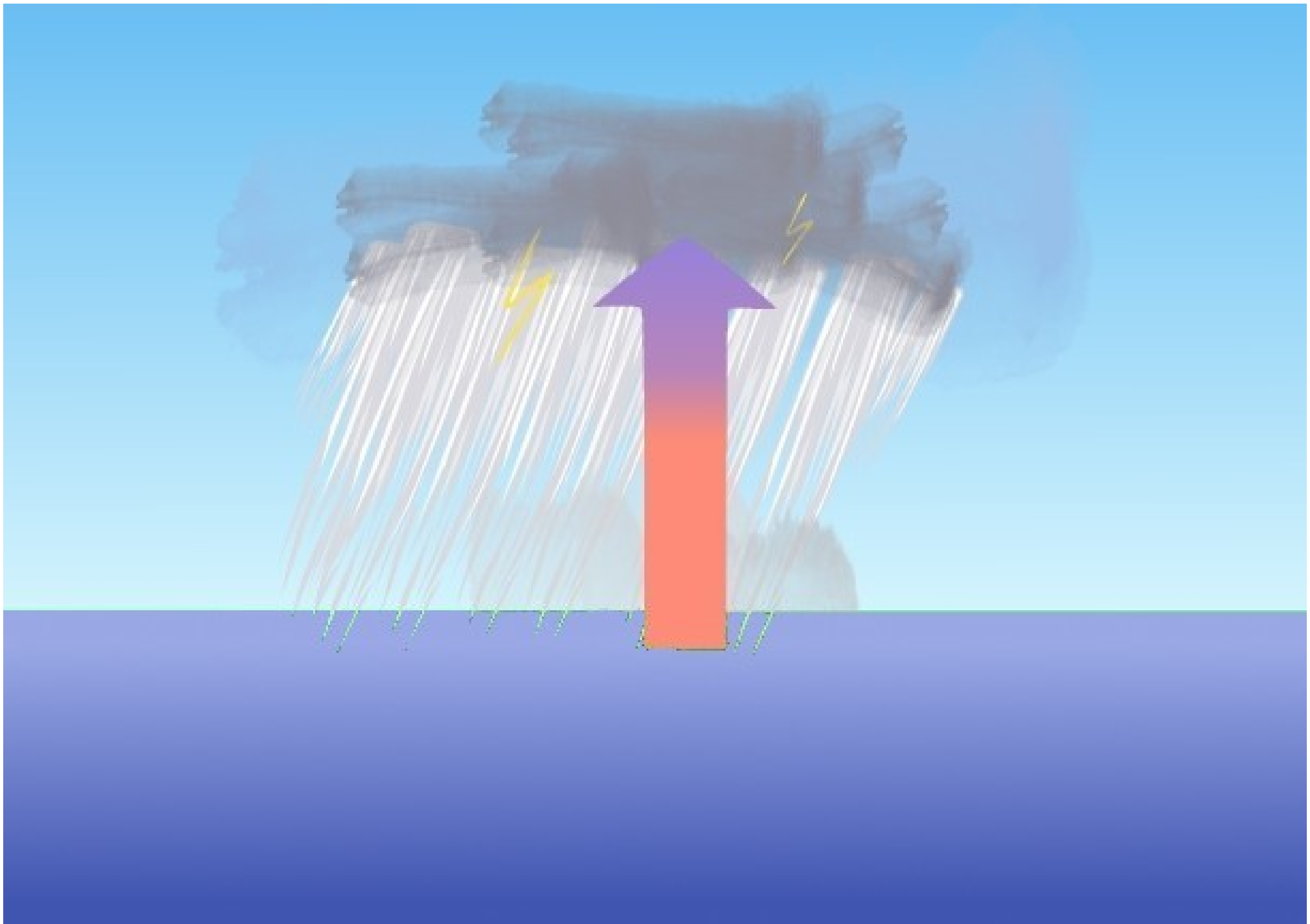


Frontal forcing

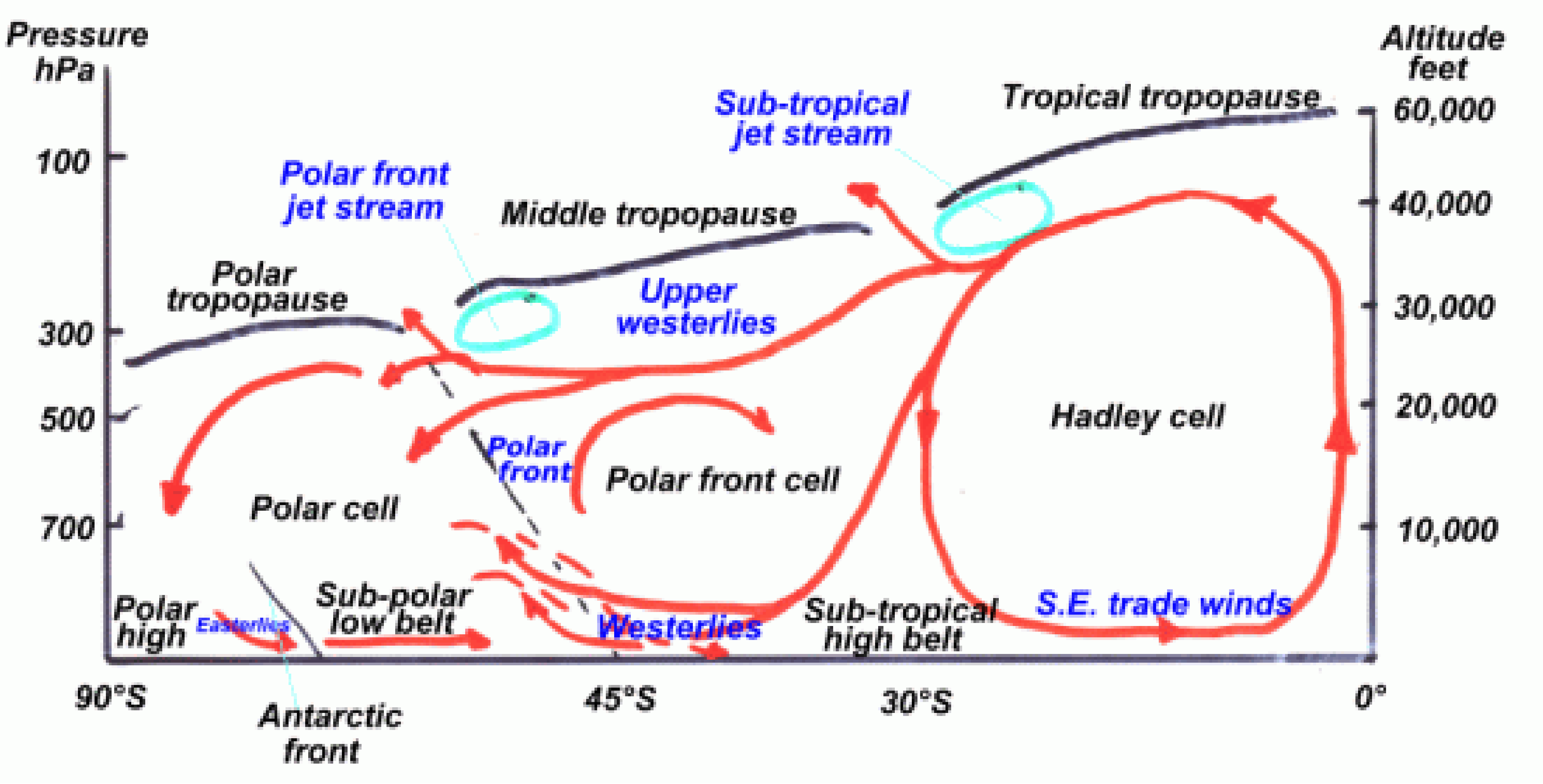




Convection



Large scale atmospheric circulation



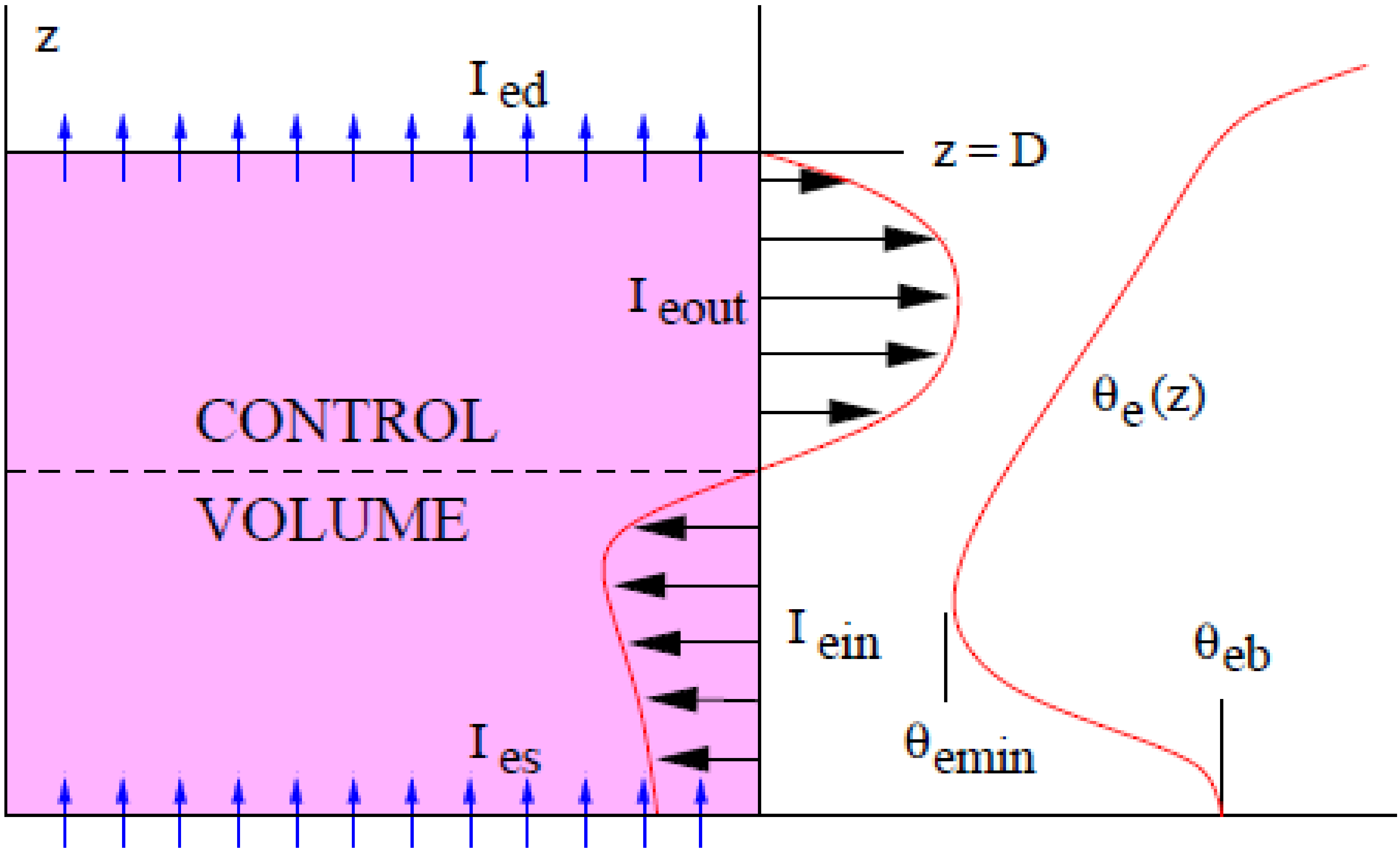
Previous work

- Neelin, Held: Modeling tropical convergence based on the moist static energy budget, *Monthly Weather Review*, **115**, 3-12 (1987)

What is new

- equilibrium → non-equilibrium state
- hypothesis = rainfall ~ saturation deficit

Analyzed situation



Governing equations

$$\frac{\partial \rho \theta_e}{\partial t} + \nabla \cdot (\rho \mathrm{u} \theta_e) + \frac{\partial \rho w \theta_e}{\partial z} = -\frac{\partial F_e}{\partial z} + G$$

$$\frac{\partial \rho r_t}{\partial t} + \nabla \cdot (\rho \mathrm{u} r_t) + \frac{\partial \rho w r_t}{\partial z} = -\frac{\partial F_r}{\partial z} - P$$

Averaged governing equations

equivalent potential temperature deficit $\Delta\theta_e$

$$\frac{\partial \rho\theta_e}{\partial t} + \nabla \cdot (\rho \mathbf{u} \theta_e) + \frac{\partial \rho w \theta_e}{\partial z} = -\frac{\partial F_e}{\partial z} + G$$

$$\downarrow \frac{1}{AD}\int_0^D \int_A dAdz$$

$$-\frac{d\overline{\rho\Delta\theta_e}}{dt} + \frac{M\delta\theta_e}{AD} = \frac{F_{es} - F_{ed}}{D} + \overline{G}$$

Averaged governing equations

saturation deficit Δr

$$\frac{\partial \rho r_t}{\partial t} + \nabla \cdot (\rho \mathrm{u} r_t) + \frac{\partial \rho w r_t}{\partial z} = -\frac{\partial F_r}{\partial z} - P$$

$$\downarrow \frac{1}{AD} \int_0^D \int_A dAdz$$

$$-\frac{\overline{d\rho\Delta r}}{dt} - \frac{M\delta r_t}{AD} = \frac{F_{rs} - R}{D}.$$

Averaged governing equations

$$-\frac{d\overline{\rho\Delta\theta_e}}{dt} + \frac{M\delta\theta_e}{AD} = \frac{F_{es} - F_{ed}}{D} + \overline{G}$$

$$-\frac{d\overline{\rho\Delta r}}{dt} - \frac{M\delta r_t}{AD} = \frac{F_{rs} - R}{D}.$$

Mass flux

averaged governing equations

$\downarrow$ $\Delta\theta_e \approx \theta_{es} L \Delta r / (C_p T_R)$

$$M = A \frac{F_{es} - F_{ed} + D\overline{G} + \theta_{es} L (R - F_{rs}) / (C_p T_R)}{\delta\theta_e + \theta_{es} L \delta r_t / (C_p T_R)}.$$

Mean saturation deficit

$$-\frac{d\chi}{dt} = -\frac{(R - F_{rs})\delta\theta_e}{D\delta r_t} + \frac{F_{es} - F_{ed}}{D} + \overline{G}.$$

$$\chi = \overline{\rho\Delta\theta_e} + \frac{\overline{\rho\Delta r}\delta\theta_e}{\delta r_t} \approx \left(\frac{\overline{\theta_{es}}L}{C_p T_R} + \frac{\delta\theta_e}{\delta r_t}\right)\overline{\rho\Delta r}.$$

Rainfall ~ saturation deficit

$$R = \frac{R_0 \chi_0}{\chi},$$

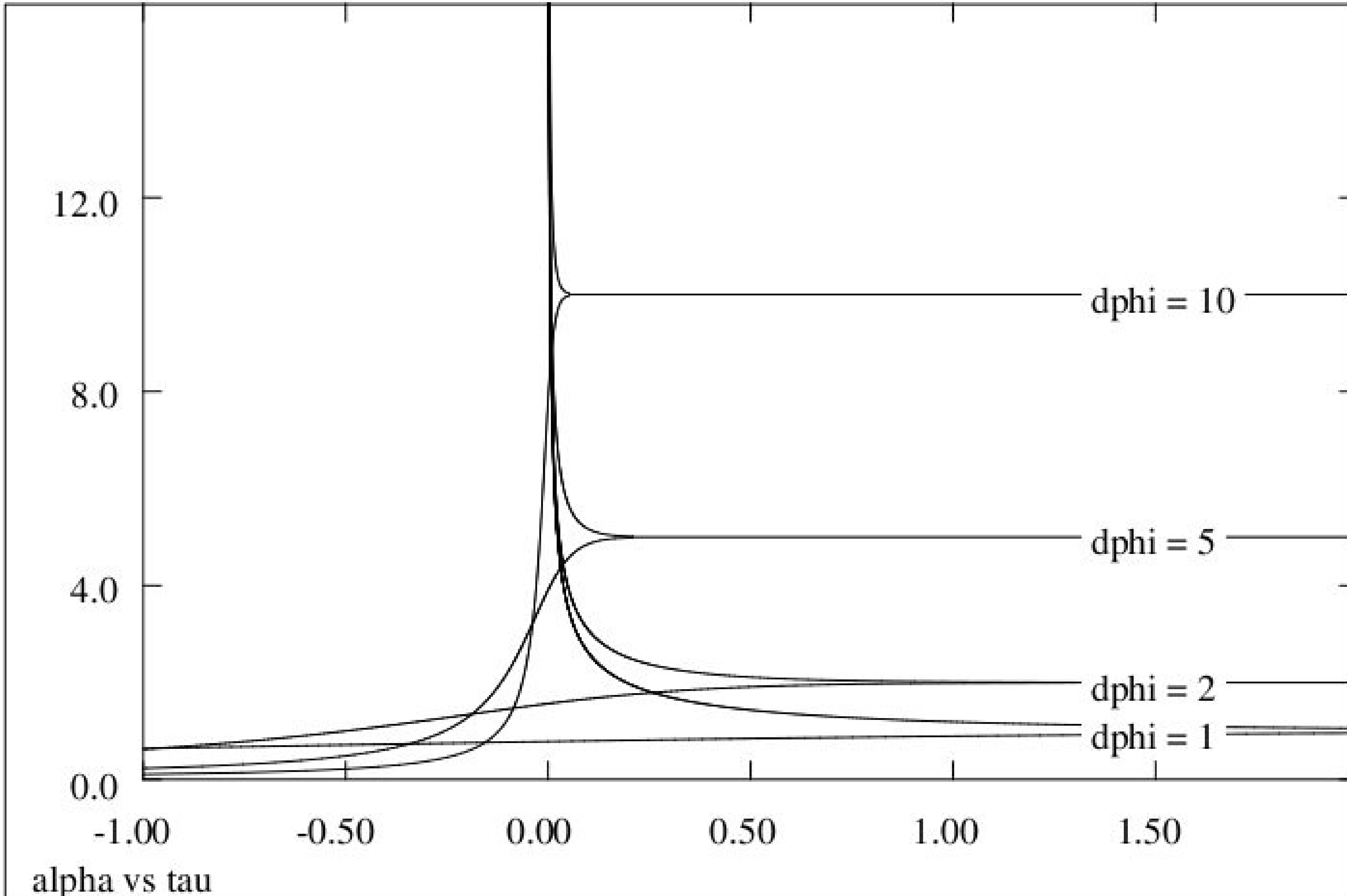
↓

$$\frac{R_0 \chi_0}{R^2} \frac{dR}{dt} = -\frac{R \delta \theta_e}{D \delta r_t} + \frac{F_{rs} \delta \theta_e}{D \delta r_t} + \frac{F_{es} - F_{ed}}{D} + \overline{G}.$$

↓ nondimensionalisation

$$\frac{d\alpha}{d\tau} = -\alpha^3 + \alpha^2 \Delta\phi$$

Full solution



Any questions?