Hazy Exoplanets in 3D : From Earth-like to Hot-Jupiter

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In this work, we couple the climate model (see A.1) with the photochemical model (see A.2) to model the effect of haze on the Archean Earth (see B), TRAPPIST-1e (see C) and WASP 39b (see D).

(A.1) Climate model

- 3D general circulation model – the Unified Model

(A.2) Photochemical model

- Earth-like: Haze prescription from 1D photochemical model – Atmos (Titan-like haze)
- Hot-Jupiters: Haze parameterisation - Eqn 1, 2 - Following Steinrueck et al. 2021, 2023 (Titan-like, Soot-like and Water-world-like haze)

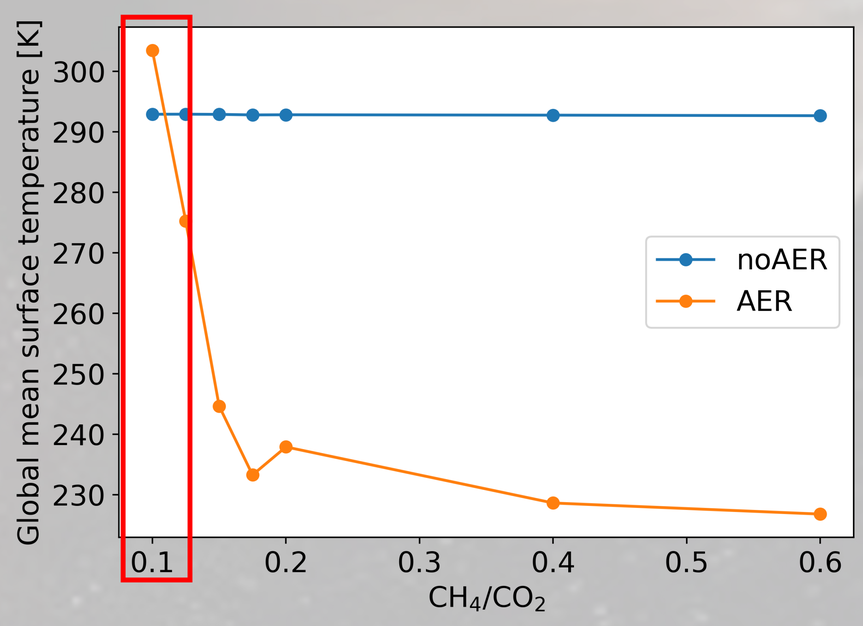
- P : Haze production term
- F_0 : Haze production rate
- θ : solar zenith angle
- p : pressure
- σ : Standard deviation
- m : Median of the distribution
- L : Haze loss term
- χ : Haze mixing ratio
- τ : loss timescale
- p_{deep} : 100 mbar

Eqn 1: $$P = F_0 g cos\theta \frac{1}{\sqrt{2\pi}\, p\sigma} \exp\left\{-\frac{(\ln(p/m))^2}{2\sigma^2}\right\}$$

Eqn 2: $$L = -\chi/\tau \quad (\text{for } p > p_{deep})$$

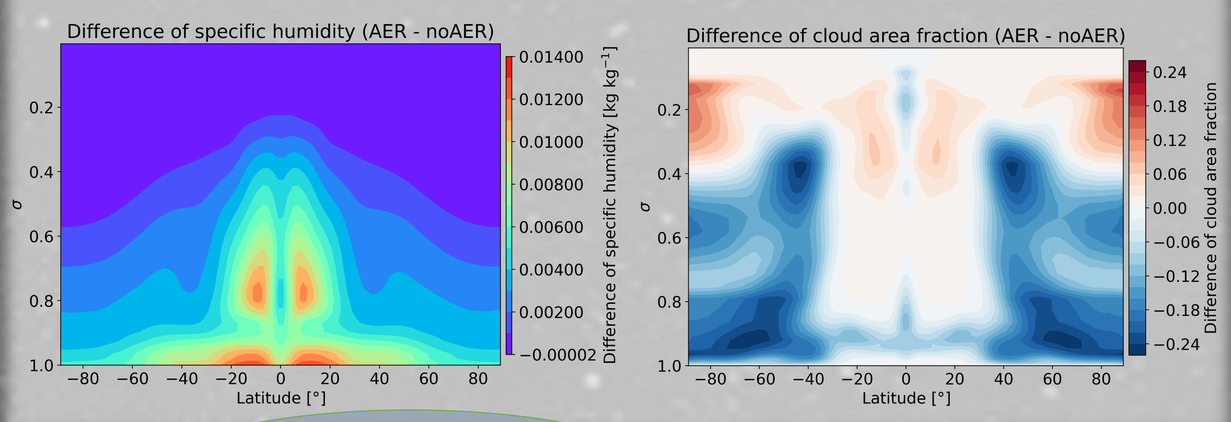
(B) Earth-Like Exoplanets : Archean Earth (Mak et al 2023)

- Thin haze layer: Global warming of up to ~ 10.6 K
- Thick haze layer: Global cooling of up to ~ 65 K



noAER – no haze
AER – with haze

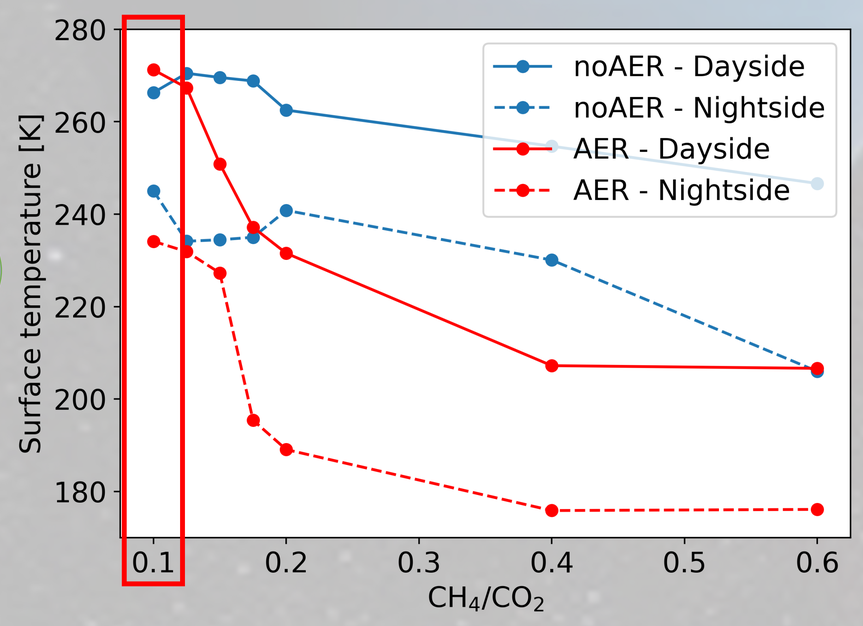
- Thin haze layer → Evaporation rate ↑ + Cloud fraction ↓
- Thick haze layer → Radiation shield



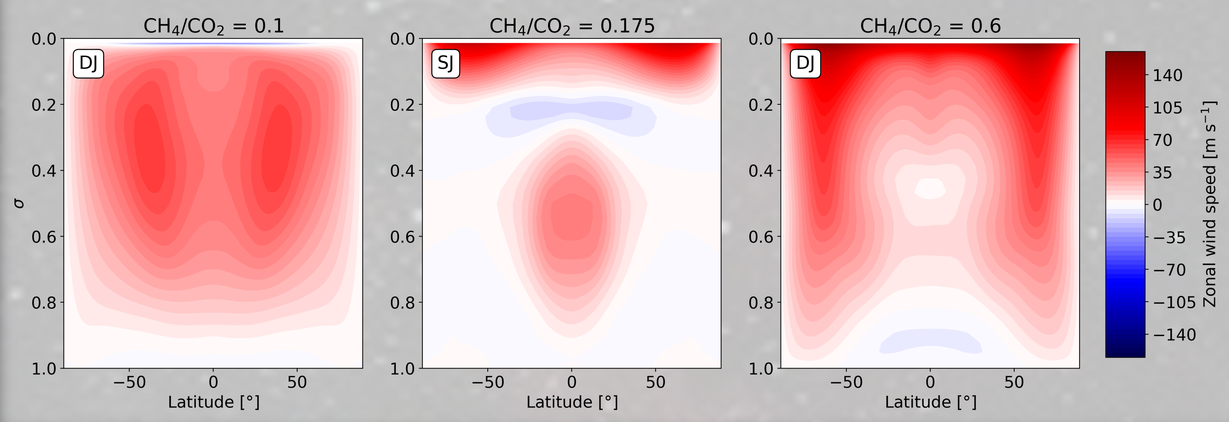
p: radiatively passive
a: radiatively active

(C) Earth-Like Exoplanets : TRAPPIST-1e (Mak et al 2024)

- Thin haze layer: Dayside warming of up to ~ 4.6 K
- Thick haze layer: Surface cooling of up to ~ 60 K

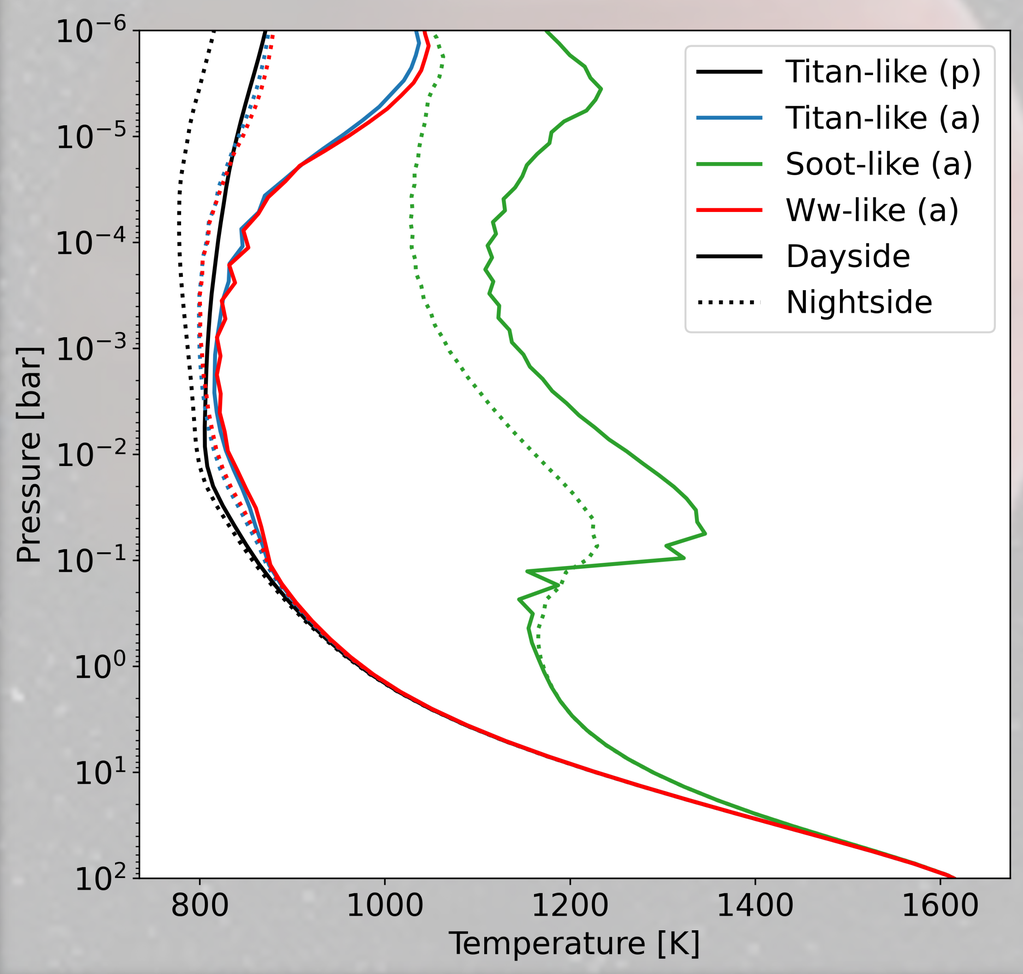


- Haze with different opacity → Drives single equatorial (SJ) /dual mid-latitude (DJ) prograde jets → Changes TP profile



(D) Hot-Jupiter: WASP 39b (Mak et al 2024 in prep.)

- All haze → Shortwave heating creates thermal inversion
- Soot (most absorbing haze) → shows hottest atmosphere



- Haze distribution dominates in the nightside (trapped in the nightside vortices)
- Higher opacity (soot) → Stronger wind → weaker haze distribution