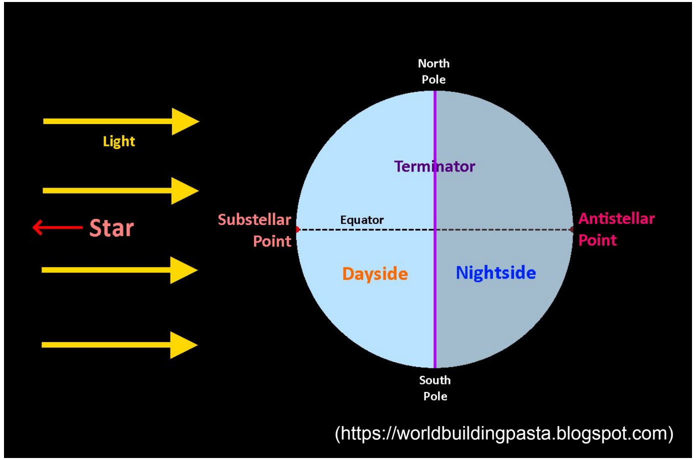
# Ambiguities in transit spectra of habitable zone rocky planets due to unknown surface conditions

**Evelyn Macdonald,** Kristen Menou, Christopher Lee, and Adiv Paradise

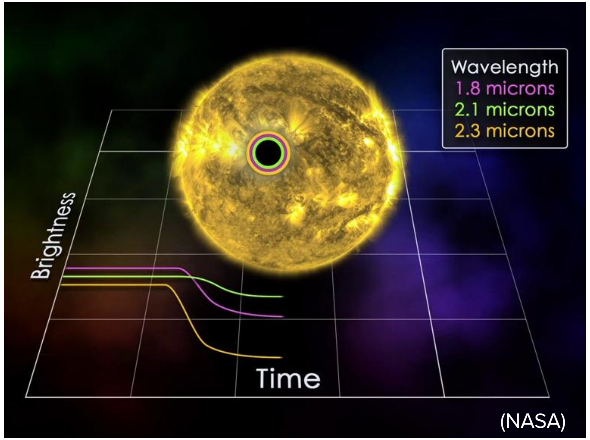
ExoExplorers Seminar Series, April 21 2023

# Context

- M-Earths:
  - Tidally locked rocky planets with M-dwarf hosts
  - Focus on those in the liquid water habitable zone
  - Atmospheres can be studied with JWST




- Transit spectroscopy:
  - Planet passes in front of star
  - Measure wavelength-dependent amount of light blocked
  - Identify molecules from planet's spectrum



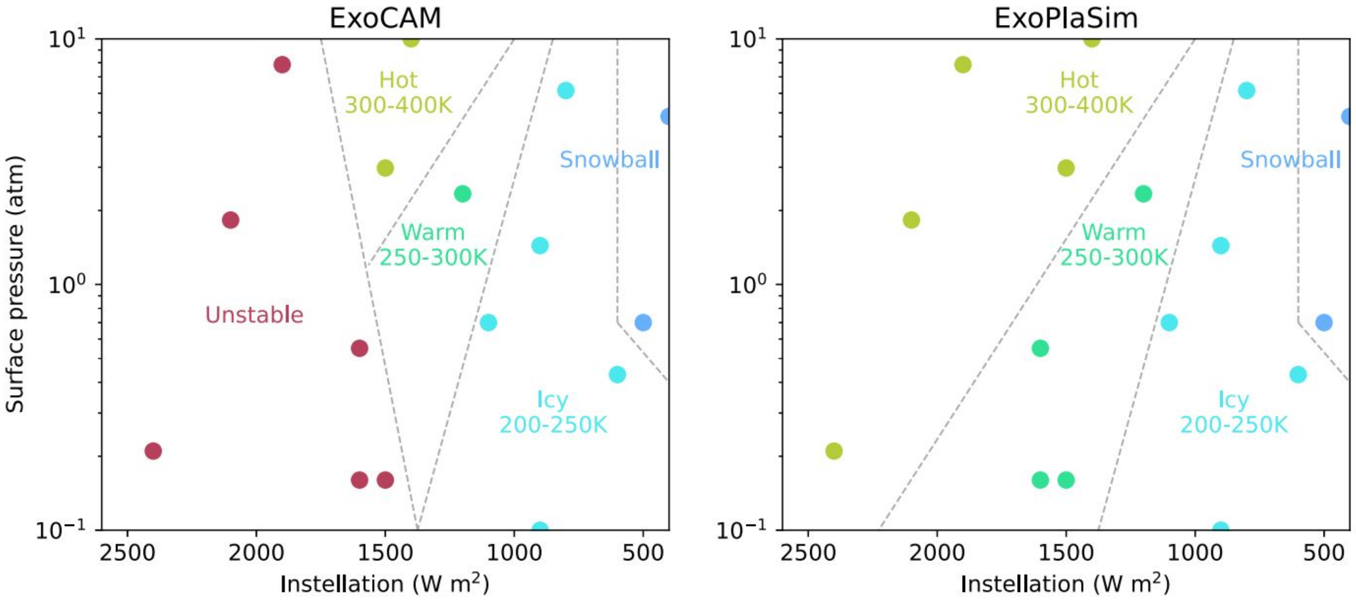
# Context

- So far:
  - Very little data about M-Earth atmospheres
  - Simulations are computationally expensive
- **Questions:**
  - **How does land influence M-Earth climates?**
  - **How does atmosphere mass influence M-Earth climates?**
  - **Can we tell these climates apart observationally?**
- Tools:
  - Climate model: ExoPlaSim[1]
  - Radiative transfer model: petitRADTRANS[2]

[1]Paradise et al. 2022
[2]Mollière et al. 2019

# Why ExoPlaSim?

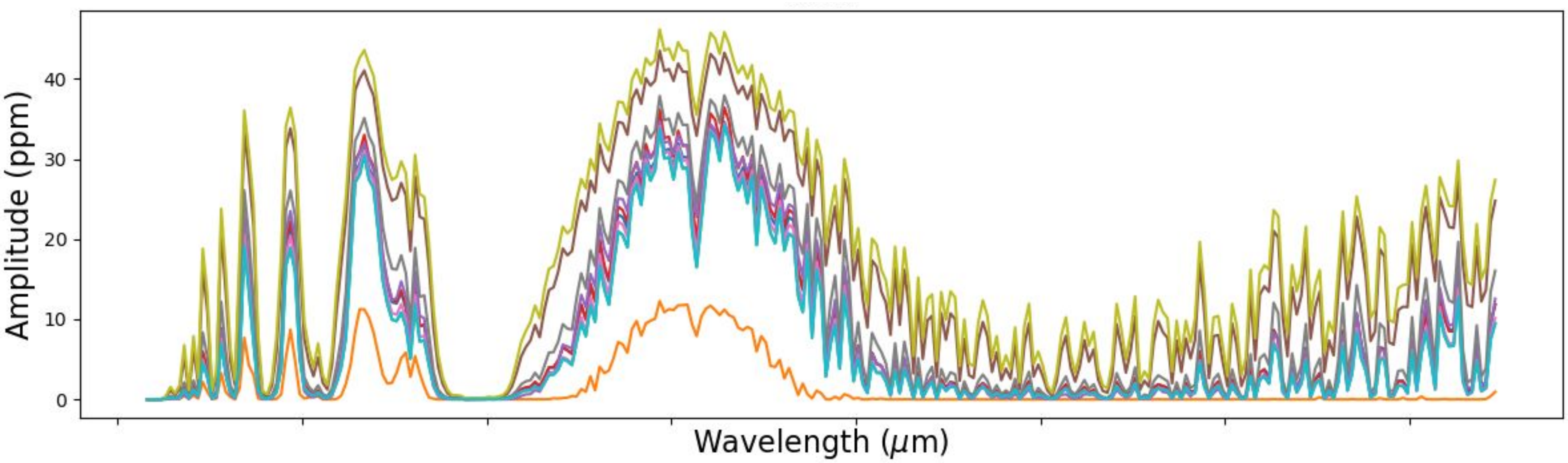
- Fast 3D general circulation model (GCM)
- Useful for large parameter space surveys and general trends
- In general agreement with other GCMs (e.g. SAMOSA intercomparison)



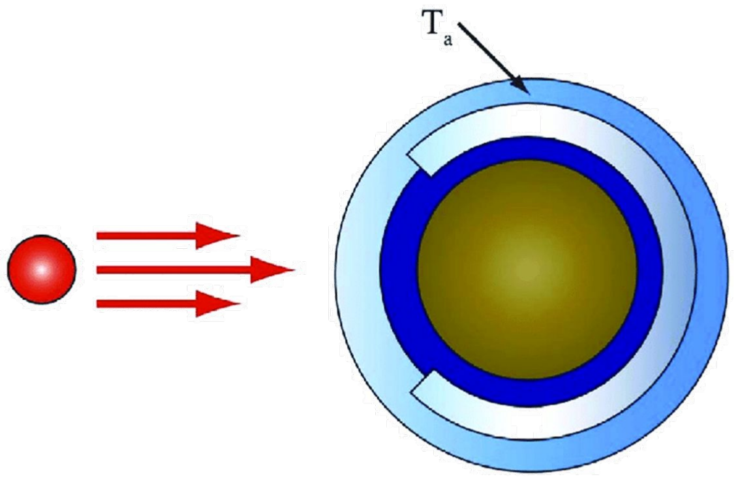

(Haqq-Misra et al., 2022)

# Sneak preview: synthetic transit spectra

- Identical simulation configurations except for surfaces and atmospheres
- **Can we infer climate from a planet’s transit spectrum?**



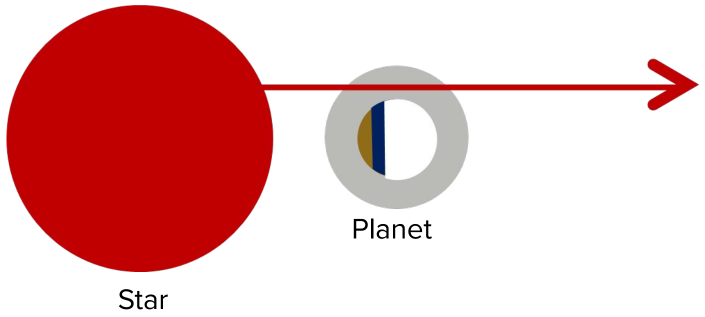
# M-Earth climates




(Pierrehumbert, 2011)

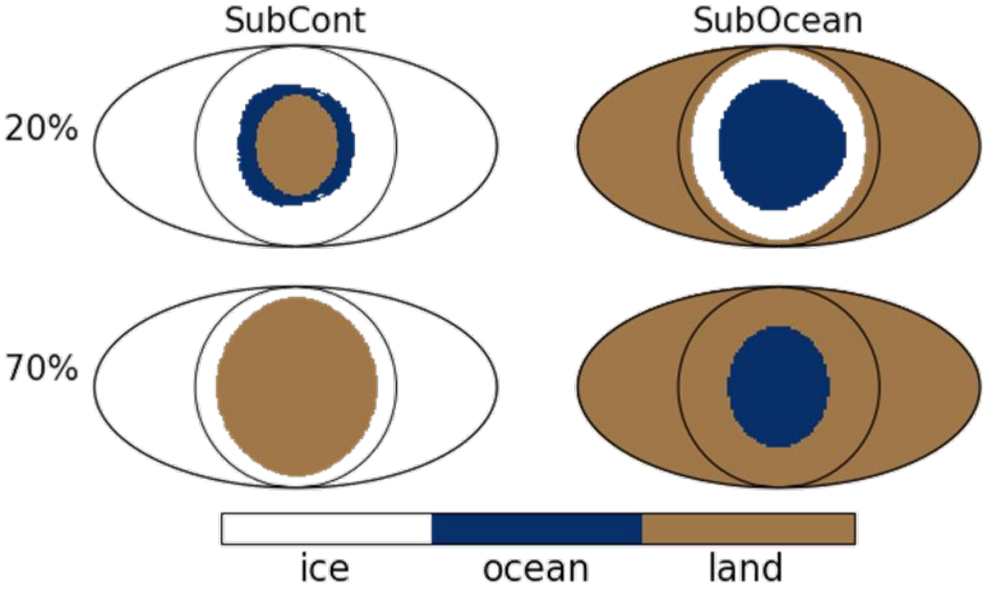
Rough approximation: “eyeball” climate

What happens if we put land in the warm region?



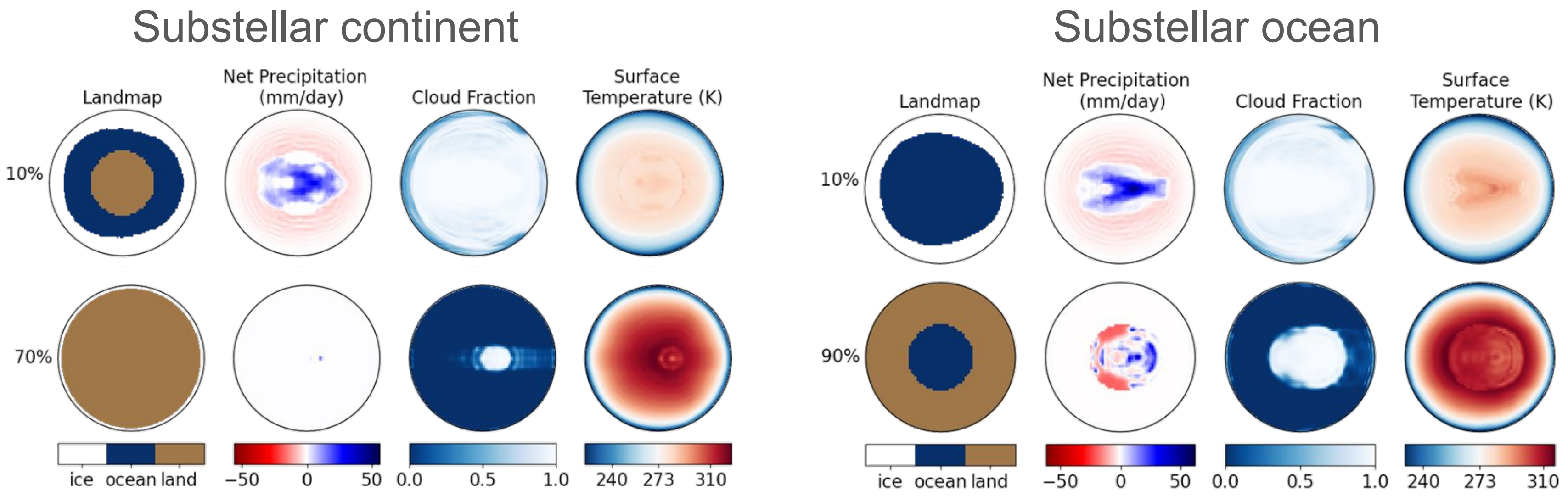
# Dayside land

- 2 opposite land configurations
- Vary size of circle
- $N_2$ atmosphere with trace $CO_2$
- **How does land configuration affect climate?**
- **Can we tell these configurations apart on a real planet?**




(**Macdonald** et al., 2022)

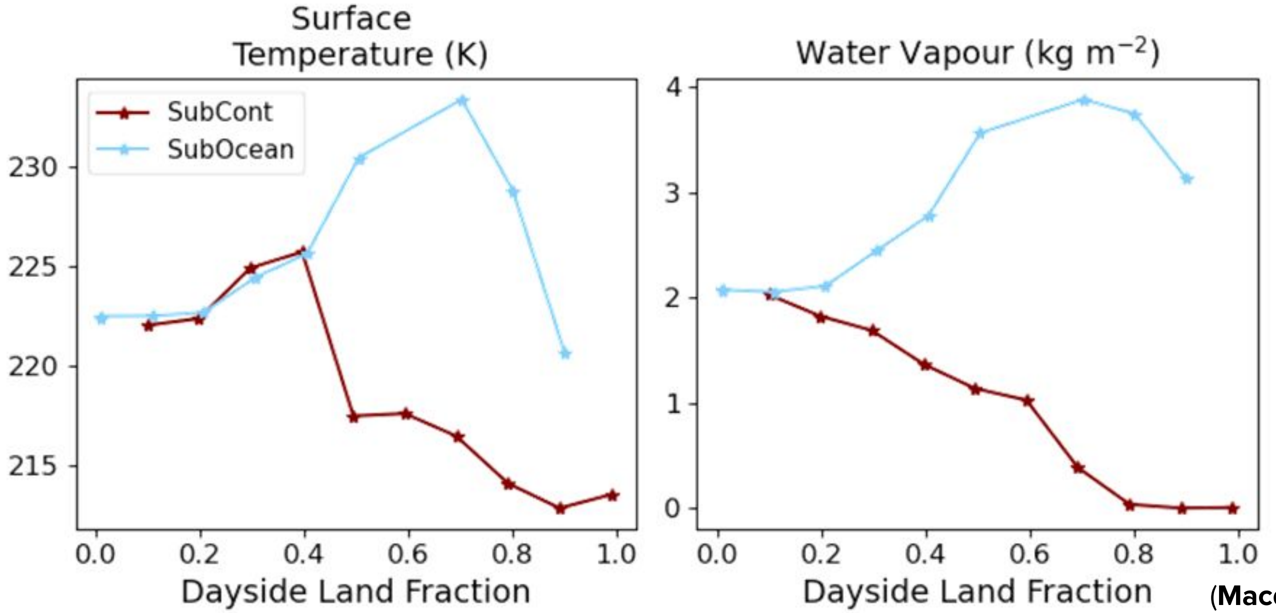
# How does land configuration affect climate?




(**Macdonald** et al., 2022)

- Based on Proxima Centauri b
- Clouds and precipitation are at the substellar point regardless of land configuration
- Large land masses are hot and dry

# How does land configuration affect climate?




(**Macdonald** et al., 2022)

- Both amount and configuration of land affect temperature and water vapour
- Largest discrepancy at partial dayside land cover due to differences in ice-free ocean aera

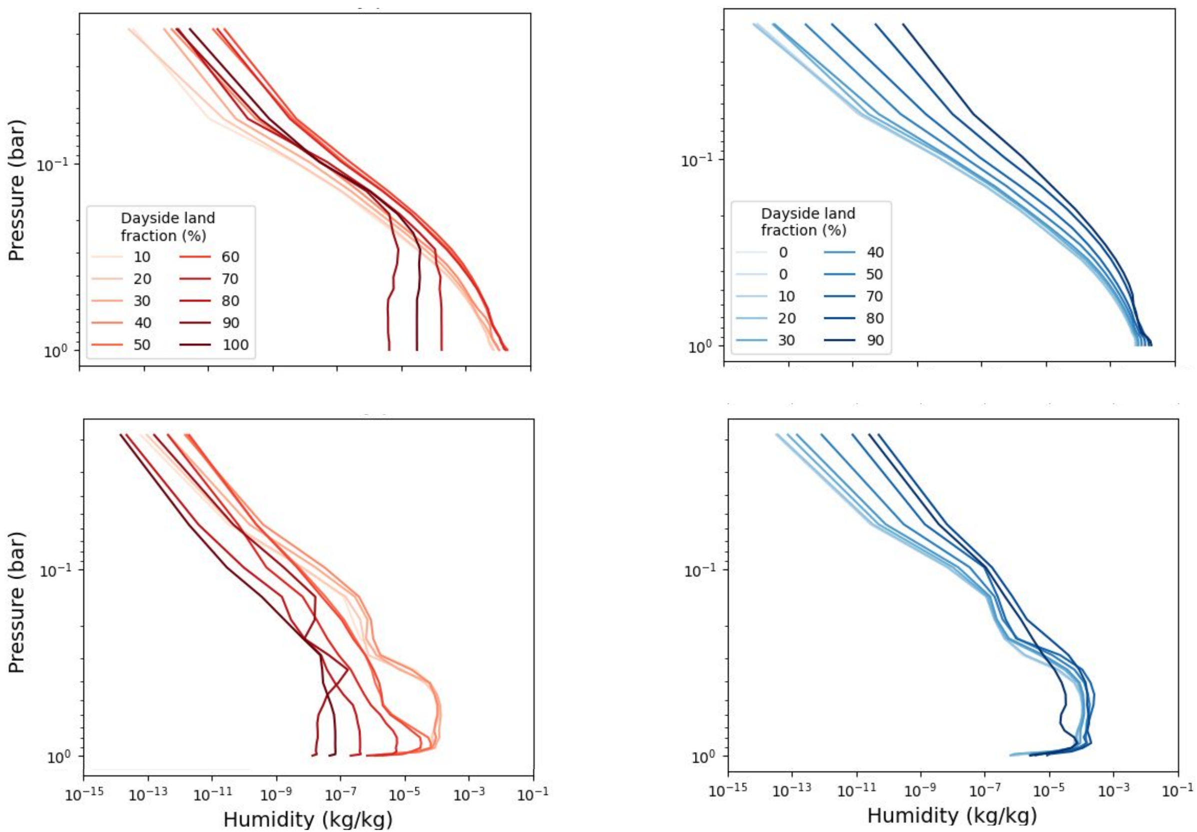
# How much water makes it to the terminator?

Substellar Continent

Substellar Ocean

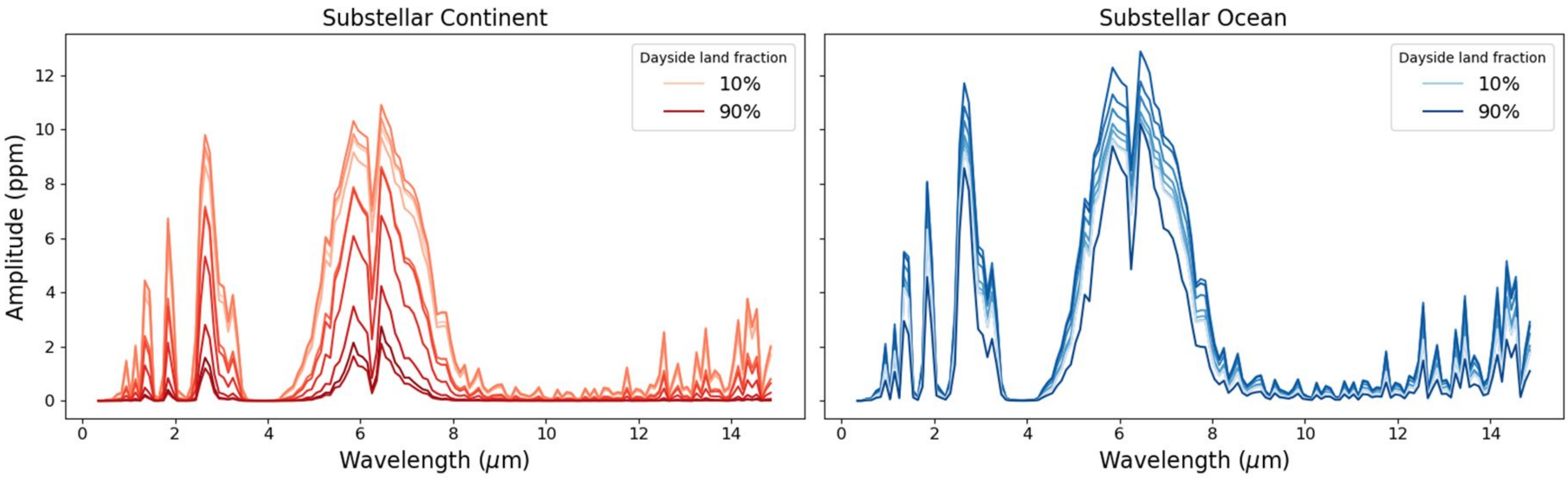
Substellar Humidity Profile

Terminator Humidity Profile



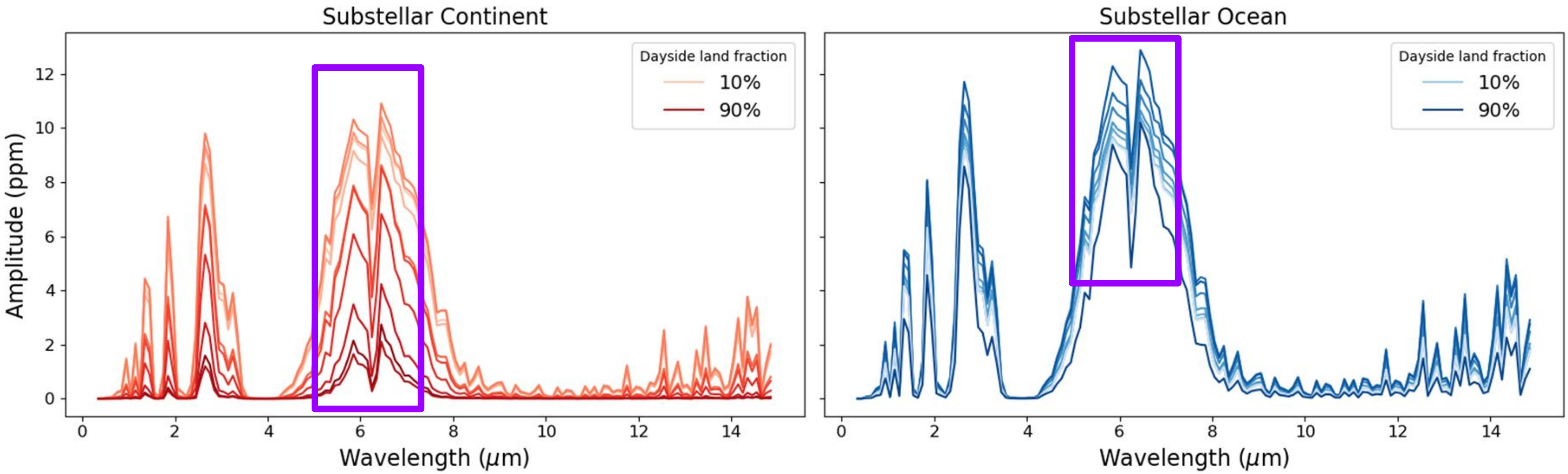
# Transit Spectra

Water vapour transit spectra for a range of dayside land fractions

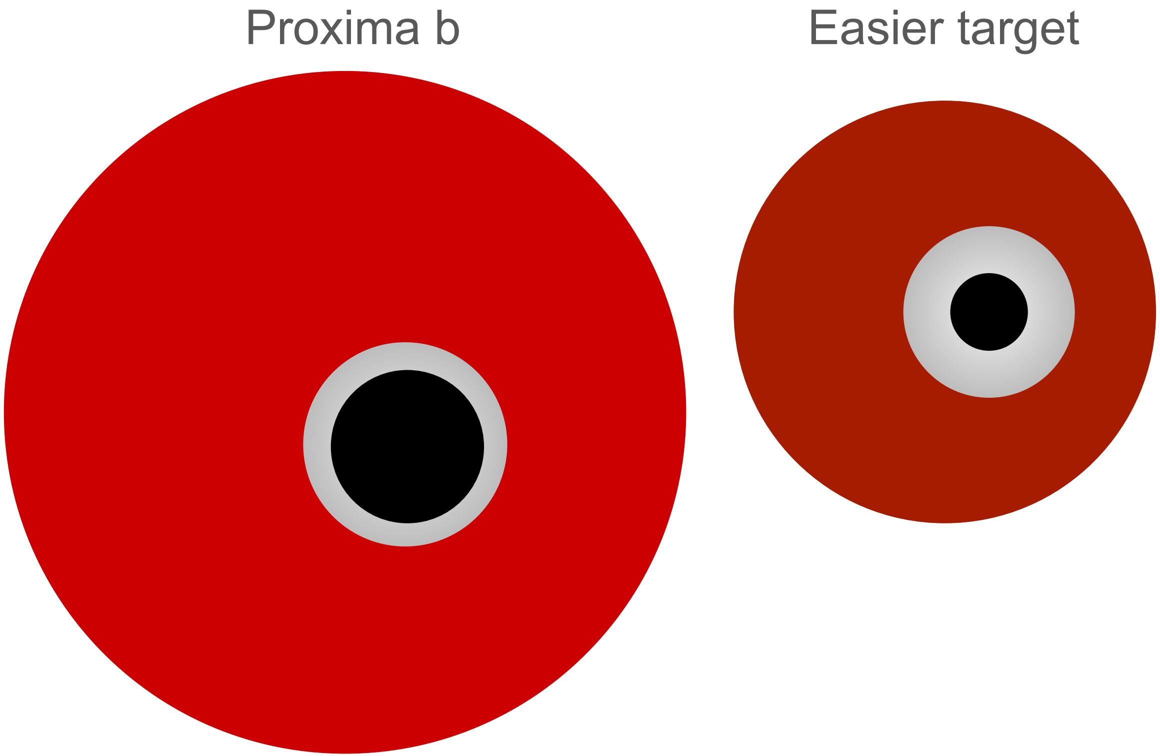


# Transit Spectra

- Amplitude of the largest water vapour feature varies much more in substellar continent models
- Water vapour would be difficult to detect in all cases



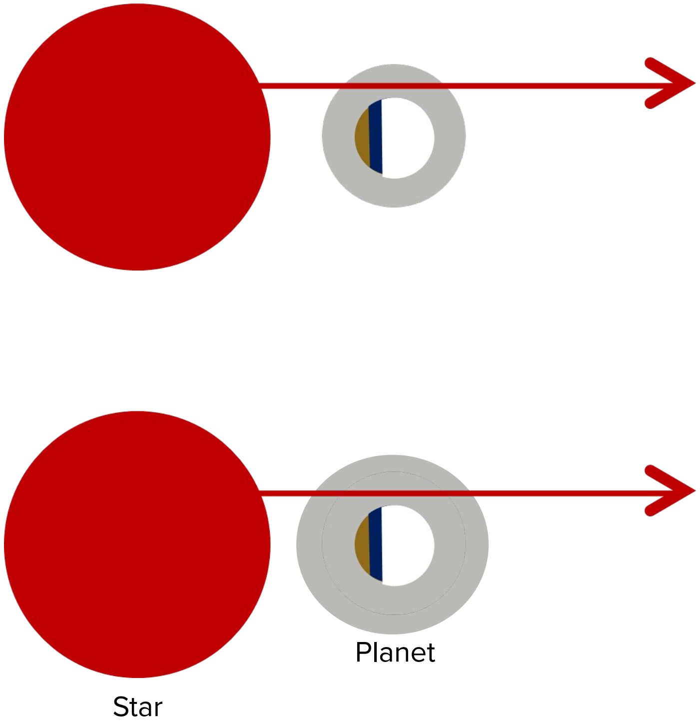
# Optimizing simulations for water vapour detectability




- **Smaller star:** larger relative planet size
- **Smaller planet:** lower gravity and larger scale height

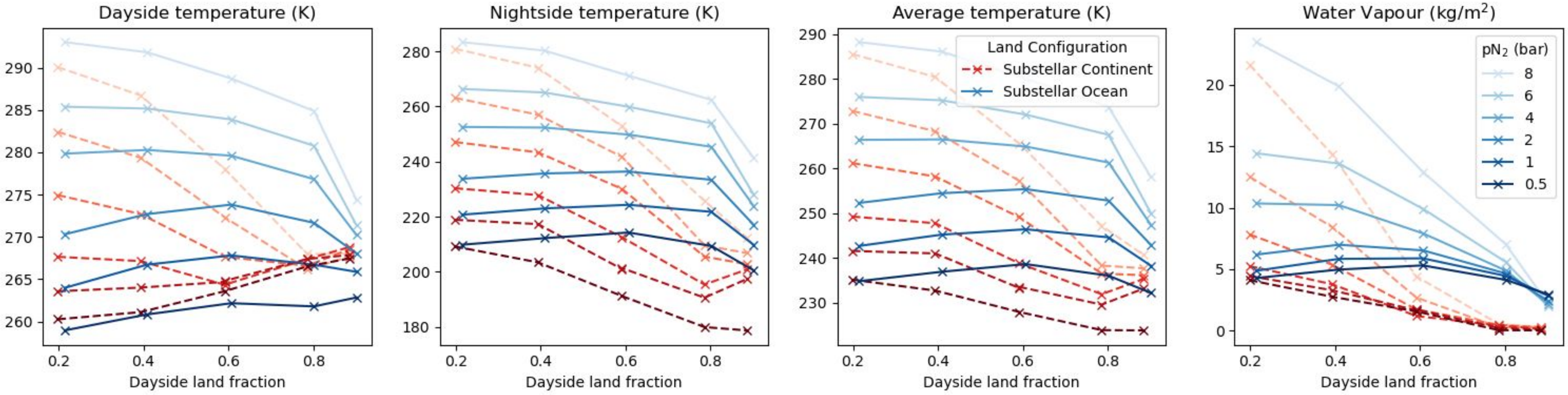
# How does atmosphere mass affect climate?

- How does the effect of atmosphere mass depend on land configuration?
- Can we disentangle these effects in observations?



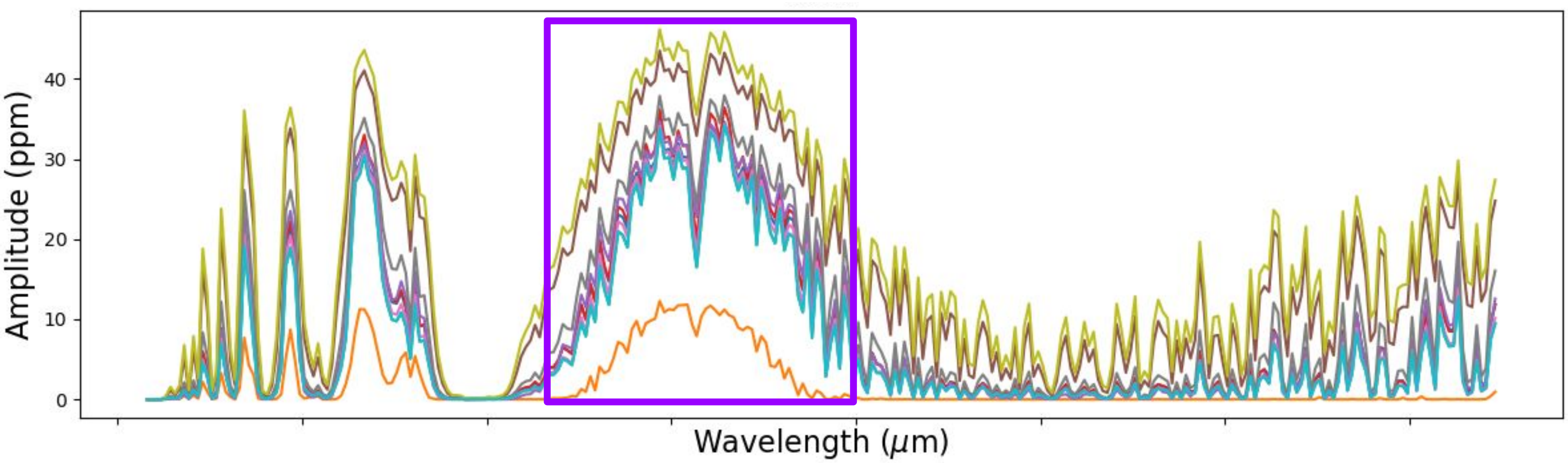
# How does atmosphere mass affect climate?

- Low substellar land fraction and high atmosphere mass contribute to warmer climates
- Land fraction and configuration still have a significant effect

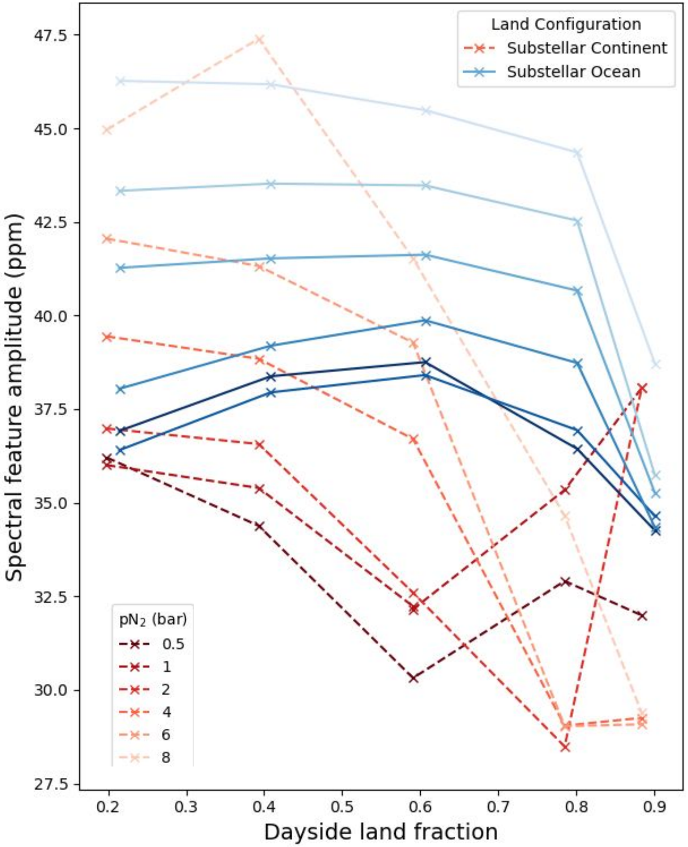


# Transit Spectra

Water vapour transit spectra for a range of dayside land fractions and atmosphere masses

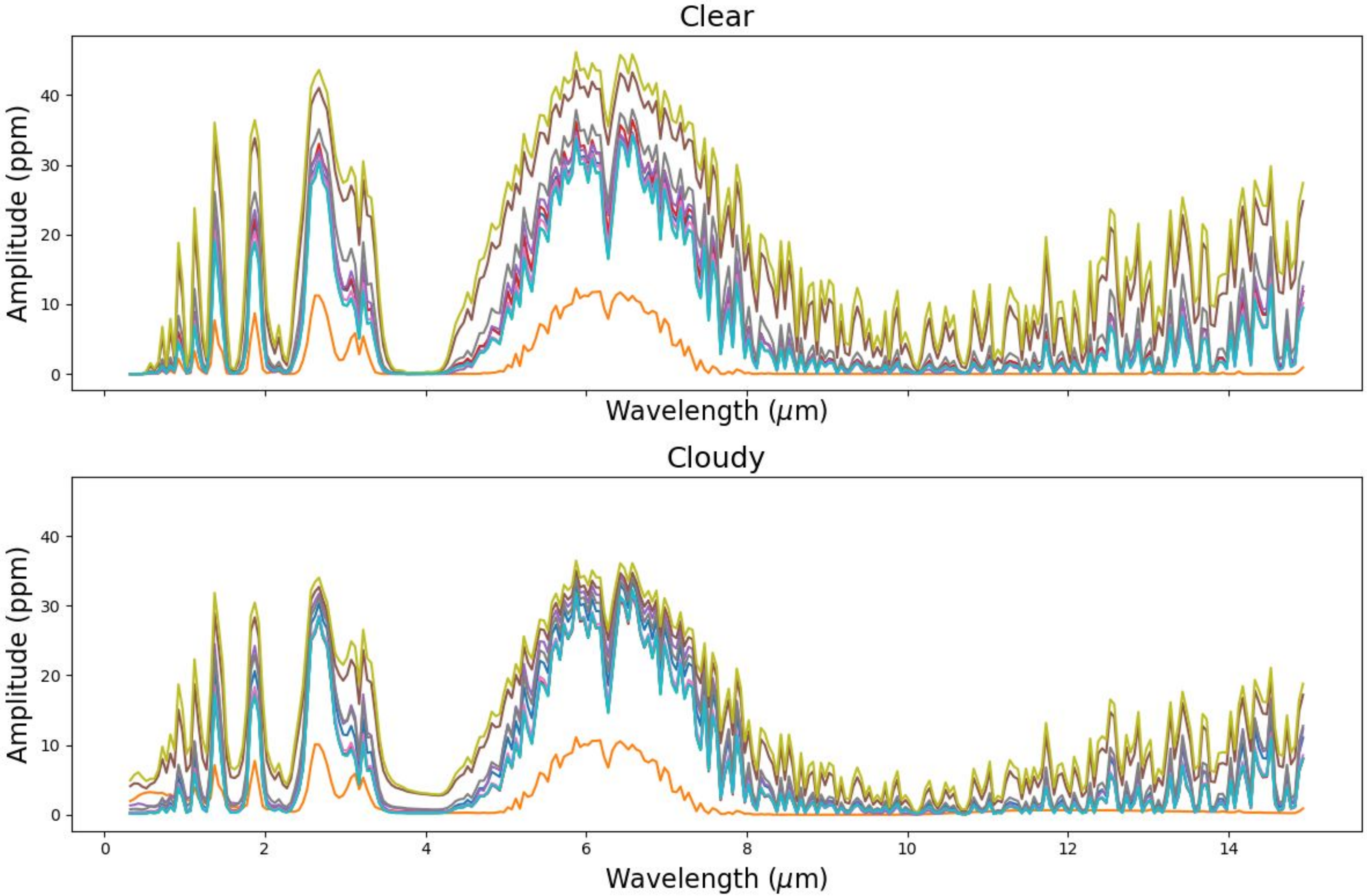


# Water Vapour Detectability



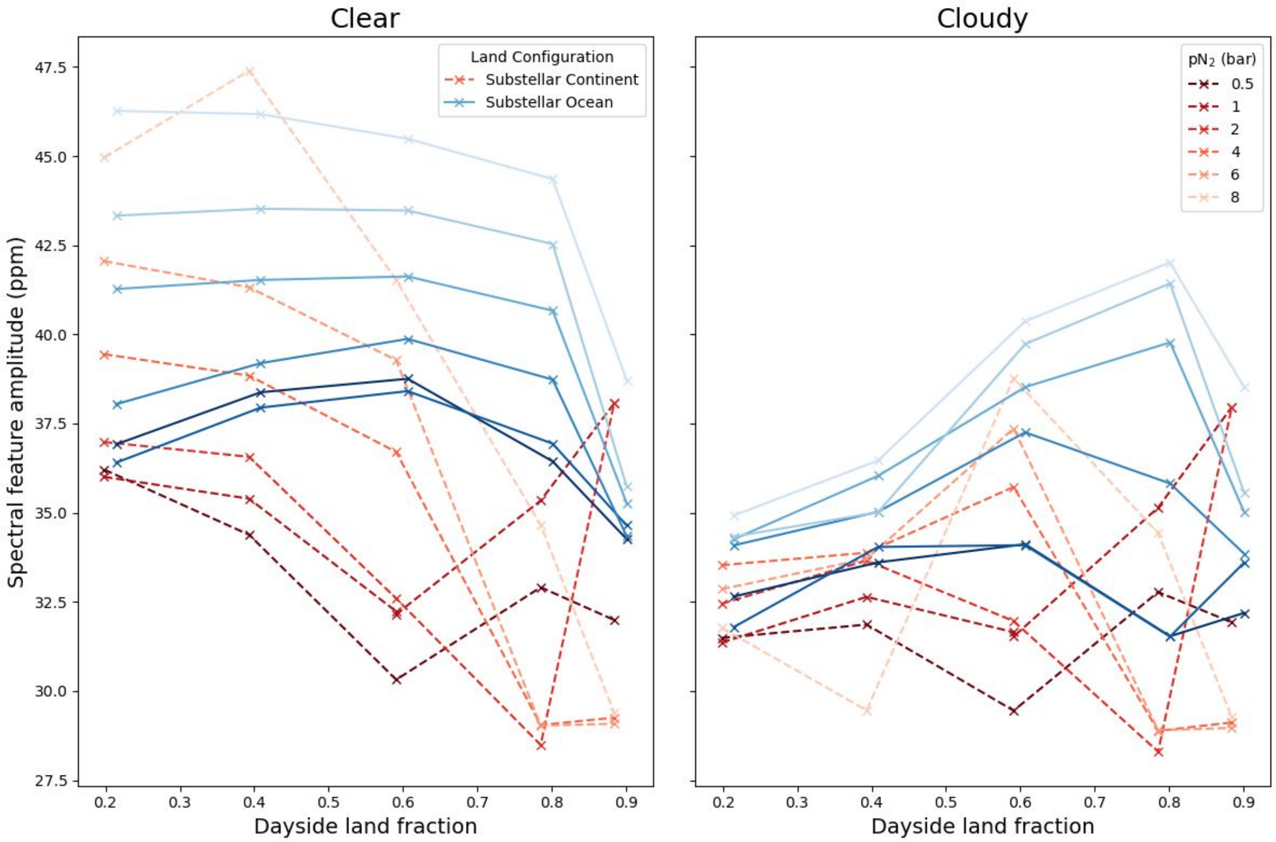

- Water vapour is much easier to detect on this smaller planet
- Very difficult to infer land fraction or configuration
- Unknown atmosphere mass adds uncertainty

# What happens when we include clouds?




- Smaller water vapour features in cloudy transit spectra
- Some spectra are more affected by clouds than others

# Clouds




- Spectral features are smaller when clouds are included
- Clouds disproportionately obscure signals from moist atmospheres
- **Result:** climate states are even more difficult to tell apart.

# Conclusions

- M-Earth parameter space has a broad range of climates
- Land and atmosphere mass have interacting climate effects
- It will be hard to tell a planet’s land configuration or atmosphere mass from its transit spectrum
- Many different climates with similar spectra could be habitable
- Small planets orbiting small stars have favourable geometry for transit spectroscopy
- **Next step:** investigate climates with massive atmospheres in more detail