Sea ice stripes on CO_2-rich aquaplanets with ROCKE-3D

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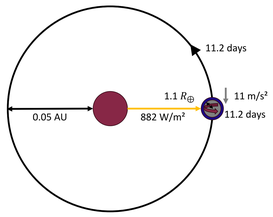
Introduction

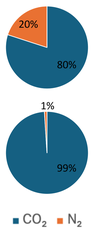
To understand observations of planetary climate, 3-D numerical GCMs + their physical interpretation are required. In this study, we demonstrate these for:

- Outer habitable zone –> low stellar flux.
- Habitability (~ surface liquid water) under high CO_2 levels (80 - 99%).
- **Dynamic oceans** deviate from 'eyeball' –> lobster [Hu and Yang, 2014].

Methods

Proxima Centauri b - 80 % & 99 % CO_2 + N_2 –> 3-D GCM:

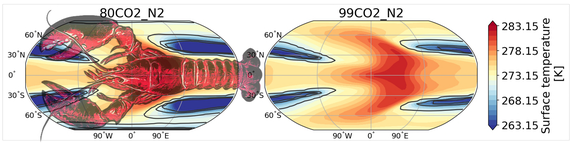




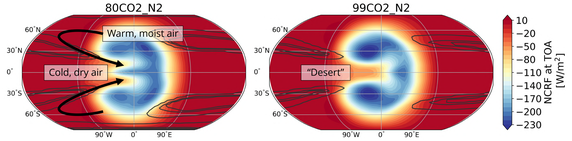
[Way et al., 2017; Tsigaridis et al., 2025]

Main results

Dynamic oceans result in surface 'lobster' temperature responses with nightside ice stripes between its claws and open ocean elsewhere, for CO_2-rich aquaplanets:



Characteristic large-scale **cloud tridents** develop aloft, propagating surface features to TOA ('blocking' + 'drying'). This can be seen in net cloud radiative forcing:

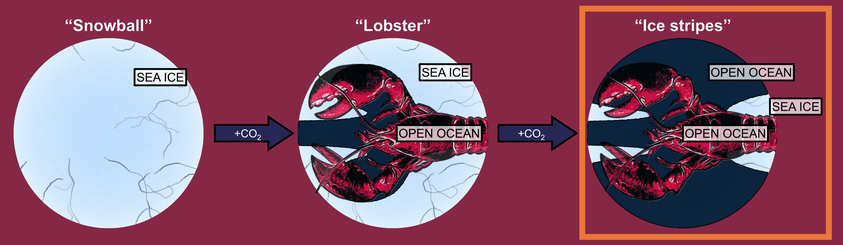


Conclusion

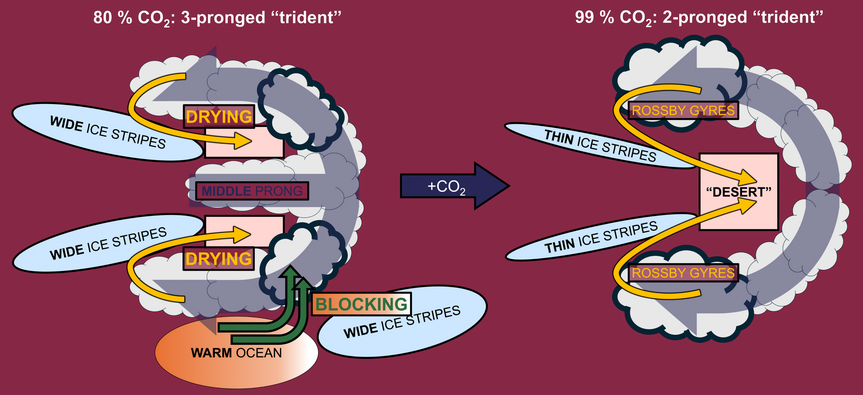
Dynamic oceans on CO_2-rich terrestrial planets result in sea ice stripes as the transition from the lobster pattern towards an ice-free planet. These stripes shape dynamics and the hydrological cycle, explainable via fundamental physical principles. Thereby, allowing to infer surface features from TOA observations. A **novel cloud trident pattern**, sensitive to these ice stripes and pCO_2 emerges. This pattern governs stellar energy distribution within the entire climate system.

Dynamic oceans on CO_2-rich aquaplanets result in

- characteristic **sea ice stripes** at the surface as an extension of the lobster pattern:



- **cloud trident** patterns aloft, sensitive to pCO_2:



Both shape surface climate and the hydrological cycle and propagate these features to **potentially observable** TOA radiative fluxes patterns.

Take a picture to download the poster.

Online presentation page (incl. OSPP voting tool).

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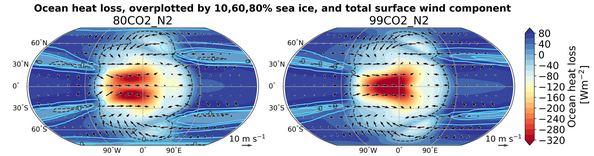
Supplementary material

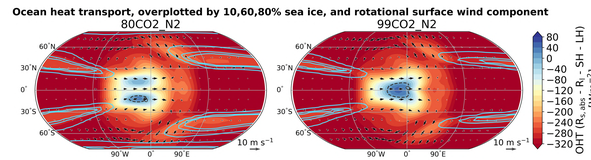
Drying effect

Ice stripes and ocean heat transport shape global heat distribution, as well as absorbed SW flux through the hydrological cycle:



⇒ Ocean heats entire nightside. Its heat uptake is shaped by the presence of the trident's middle prong. Ice stripes exhibit diverging surface wind –> dry, cool air encounters warm ocean –> moisture uptake and cooling of surface.

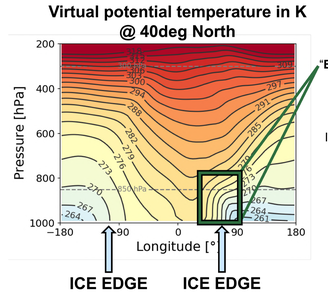
Ocean heat transport (OHT) may be approximated via surface energy budget as *abs. SW - net upward LW - Sensible Heat - Latent Heat* (see also Yang et al., 2019):



⇒ Rotational surface wind component (Rossby gyres) forces dayside extension to high latitudes. Rotational component transports air towards ice stripes –> drying and cooling –> diversion towards higher latitudes via thermal wind shear aloft –> higher substellar latitude for wider ice stripes –> +desert separation –> middle prong. Only these desert regions are origins of OHT.

Blocking effect

Virtual potential temperature contours ~flow lines:



"**Blocking**" of horizontal flow, forcing moist air to higher altitudes:

Wider ice stripes
⬇
Increased cloudiness adjacent to ice stripes
+
Sharp eastward cloud pattern limit

Trident base

⇒ Wider ice stripes force increased vertical water vapour transport, preserving their tips, and thickening reflective clouds at the trident's base.

Acknowledgements

Lobster figure: www.edwardfielding.com
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