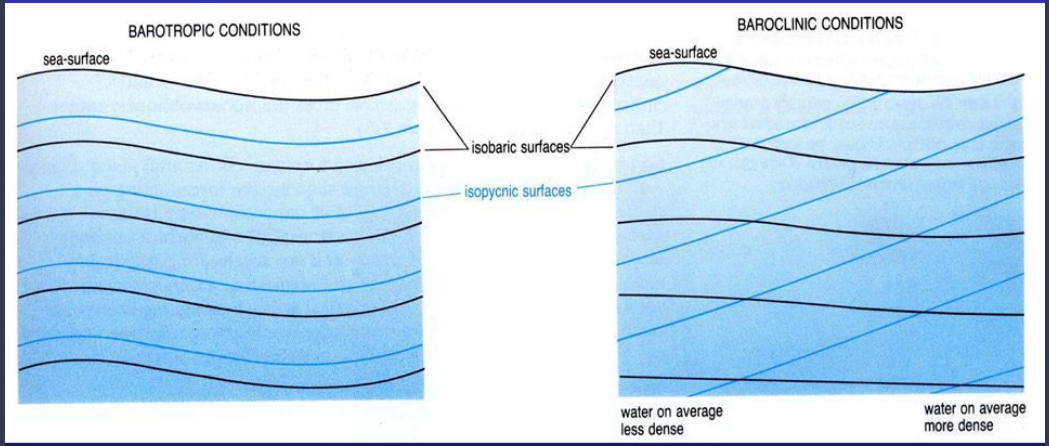
Annular modes of variability in the atmospheres of Mars and Titan

A paper by J. Michael Battalio and Juan M. Lora

Some quick definitions

- Annular Modes: They’re hemispheric scale patterns with variability in atmospheric flow.
- Barotropic: A Barotropic fluid has isopycnals (constant density) which don’t cross isobars (constant pressure). Hence, the lines are parallel.
- Baroclinic: Lines are NOT parallel. There’s a vertical component. The atmosphere is usually Baroclinic in the midlatitudes.

Baroclinic vs. Barotropic



Do annular modes have the same importance on Mars and Titan as they do on Earth?

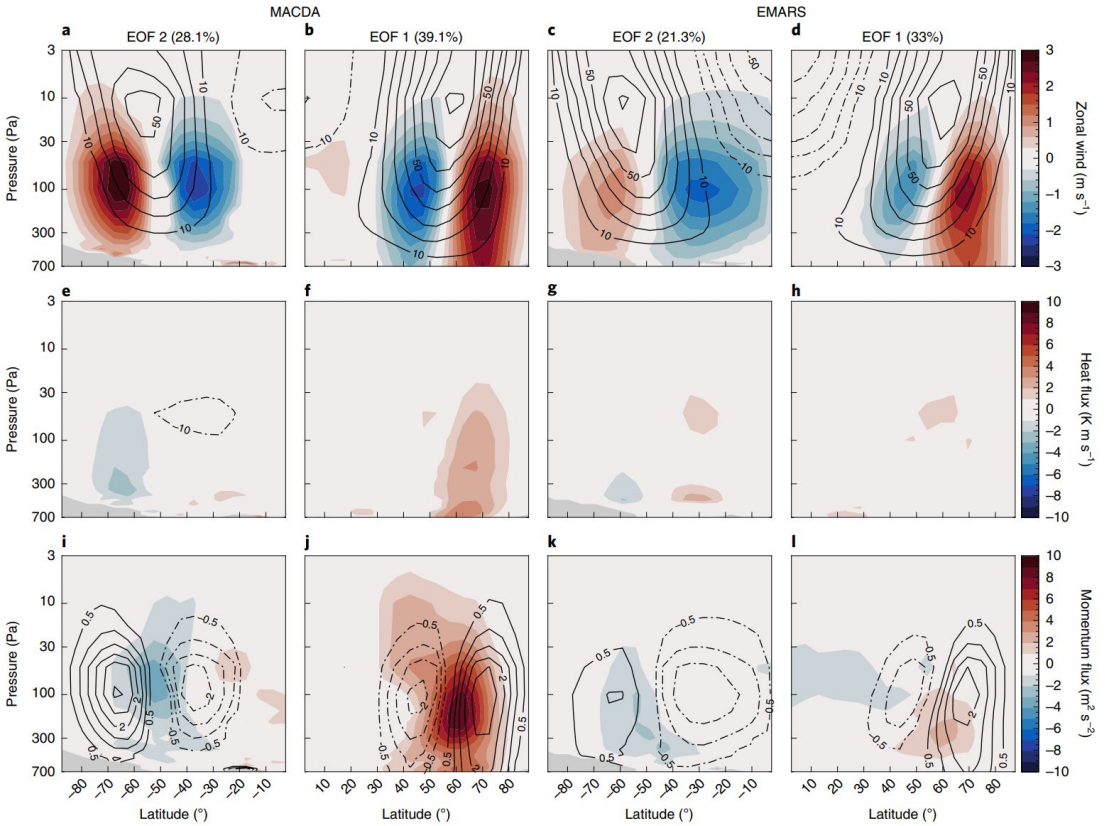
- This is the main motivation behind the paper
- Much of the internal variability in Earth's atmosphere is explained by annular modes. So naturally, we ask "What about other planets"? Battalio and Lora asked this question with a focus on Mars and Titan.

Martian Annular Mode in zonal wind

- Annular modes explain most of the variability in the mid to high latitudes during fall and winter
- This was done through EOF Analysis
- This annular mode is specifically in the zonal-mean zonal wind (U-AM). This is a barotropic feature
- The U-AM has two spatial structures, a dipolar structure (Northern) and a mono-polar structure (Southern)

Figure 1

- Figures a-d show the dipolar structure
- Six figures on the right are obtained from MACDA and left six figures are EMARS.



Martian Annular Mode in eddy kinetic energy

- There’s also a baroclinic annular mode identified in the Martian atmosphere which explains variability of the EKE.
- Named the “zonal-mean EKE (EKE-AM)”, it represents Earth’s Baroclinic mode.
- This also has multiple spatial patterns.
- It’s important to understand that the EKE-AM and U-AM DON’T act independently (they’re not decoupled). Therefore, it is not accurate to say that the EKE-AM is strictly baroclinic. Depending on the period of the dominant waves, the transient eddies grow barotropically and baroclinically.

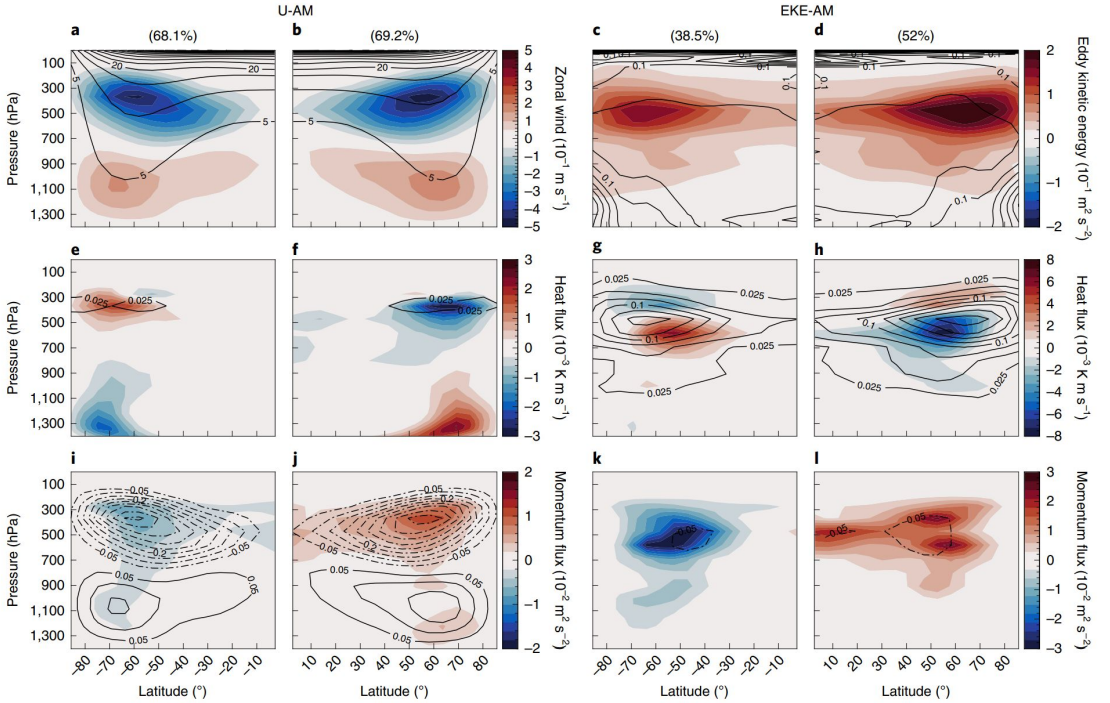
The impact of Mars’ annular modes on its dust activity

- Like precipitation is linked to Earth’s annular modes, dust activity is thought to be linked to Mars’ annular modes.
- Peaks of dust activity in the northern hemisphere are observed before the EKE-AM

What about Titan?

- Unfortunately, the same amount of observations cannot be made for Titan due to a lack of reanalysis (check ‘Methods’ section). However, a circulation model is available.
- Evidence should be approached with caution.
- Titan also has U-AM and EKE-AM. The U-AM is dipolar, similar to Mars’, but explains more and is stacked vertically. The EKE-AM is also different from the Martian EKE-AM.
- However, they’re useful in predictions still remains in question.

Figure 5


U-AM
EKE-AM
a
(68.1%)
b
(69.2%)
c
(38.5%)
d
(52%)
e
f
g
h
i
j
k
l
Pressure (hPa)
Latitude (°)
Zonal wind (10^{-1} m s^{-1})
Eddy kinetic energy (10^{-1} m^2 s^{-2})
Heat flux (10^{-3} K m s^{-1})
Momentum flux (10^{-2} m^2 s^{-2})

What does this mean for the rest of the solar system?

- All of these findings are exciting, but can we get more out of them?
- Annular modes are extremely useful for understanding and predicting weather patterns.
- Seeing that they exist on three bodies in the solar system and are useful in all of them, there's an implication that perhaps they are useful everywhere in the solar system. Only time will tell, but it's exciting to see these progressions and what could come next!

Methods

- For Mars, the MACDA and EMARS data sets were used. These are the most popular datasets along with OpenMARS.
- Due to a lack of observations of Titan’s atmosphere, Battalio and Lora were forced to use TAM, The Titan Atmospheric Model.
- Empirical Orthogonal Function (EOF) was used to identify the annular climatic variability within Earth, Mars, and Titan.

References & Helpful links

- https://www.atmos.colostate.edu/~davet/ao/introduction.html
- https://glossary.ametsoc.org/wiki/Welcome
- https://people.earth.yale.edu/sites/default/files/battalio_lora_2021_annular_modes_of_variability_in_the_atmospheres_of_mars_and_titan.pdf
- https://www.youtube.com/watch?v=slZKmmjkiac&t=457s
- Picture on slide 3: https://slideplayer.com/slide/4985047/
- https://www.youtube.com/watch?v=cIRDtJ-0GN0&t=17s
- https://www.youtube.com/watch?v=ZPfub1i8A08&t=26s

More References

- https://atmos.washington.edu/~dennis/552_Notes_4.pdf

Thank you!

Any questions?