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A5 6 Winds of Arrakis

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Abstract

In the book series 'Dune', the planet Arrakis is home to major sandstorms that are amplified by the planet's rotational motion, these being referred to as 'Coriolis storms'. We investigated the magnitude of the Coriolis force and hence the total vertical pressure gradient force necessary to produce storms of this magnitude. Per unit mass, it was found that a total Coriolis force of $F_c \approx 0.02$ ms^{-2}, and hence a vertical pressure gradient force of $\approx$ -0.026 ms^{-2} was required to produce wind speeds that facilitate these weather conditions.

Introduction

In the book series 'Dune', Arakkis is a planet that consists almost exclusively of dry dune deserts that stretch across its surface. It is home to an abundance of 'Spice', an awareness spectrum narcotic produced as a by product of natural processes of native life, which is an essential tool for interstellar travel [1]. Acquiring this valuable resource is made hard by the planet's harsh weather conditions, mainly the extreme temperatures and violent dust storms. We chose to investigate these dust storms, referred to as 'Coriolis storms', produced by the rotational motion of the planet itself, facilitating wind speeds of up to 700 kmh^{-1} ($\approx$ 194 ms^{-1}) [2]. Our aim is to determine the vertical pressure gradient force per unit mass necessary to induce dust storms of this size.

Calculations and Discussion

To begin, it is important to determine some of the key planetary parameters needed to compute the values we need. We assumed that Arakkis is similar in size to Earth with a planetary radius of $r_A \approx 6000$ km and that day length on Arakkis is $\sim$ 22 hrs [2], from this the angular velocity of the planet was computed using:

$$\Omega = \frac{2\pi}{T} \tag{1}$$

Where Ω is the angular velocity (rad s^{-1}) and T is the rotation period of Arrakis (s). Substituting in the known value of the rotation period provides a value of $\Omega \approx 7.9 \times 10^{-5}$ rad s^{-1} (2.s.f). This value of the angular velocity allows us to then calculate the Coriolis parameter and hence, the Coriolis force F_c. The Coriolis parameter for Arrakis will be given by $f = 2\Omega \sin(\phi)$, where Ω is as previously stated and ϕ is the latitude (°). This can then be used to determine the Coriolis force per unit mass:

$$F_c = 2\Omega \sin(\phi) u \tag{2}$$

Where all variables are as previously stated and u is the wind speed of the storm ($\approx$ 194 ms^{-1}). Assuming also a mid-latitude of $\phi = 45°$ (due to the dominant wind balance in the horizontal direction), this gives a value of $F_c \approx 0.02$ ms^{-2} (2.d.p). When comparing with the average Earth value for the Coriolis force of $\approx$ 0.011 ms^{-2}, using the same calculation, our value for Arrkis seems feasible. In order to evaluate the pressure gradient force, we assumed that Arrakis is a moderately-rotating body, similar to Saturn's moon Titan, furthermore we can model it using simplified horizontal momentum relations assuming gradient wind balance [3]. The co-ordinate system we chose to adopt is illustrated in Fig.1.

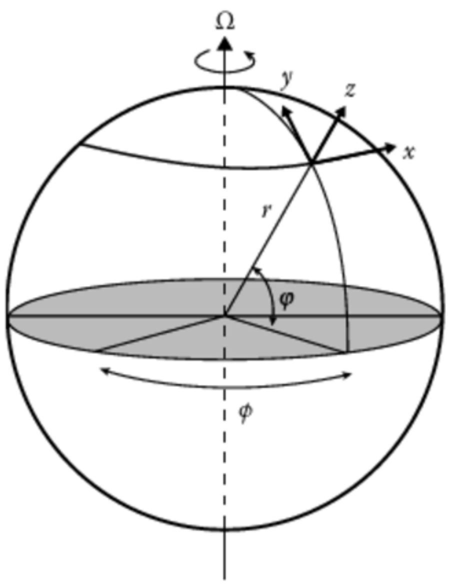

Figure 1: Local Cartesian co-ordinate systems for a spherical planet, from Sanchez Lavega (2011).

The centrifugal force per unit mass, F_g, for the planet must also be calculated in order to obtain the pressure gradient force. This is done using:

$$F_g = \frac{u^2 \tan(\phi)}{r_A} \tag{3}$$

Where all variables are as previously stated. Similarly assuming mid-latitude, this yields a value of $F_g \approx 0.0063$ ms^{-2} (4.d.p). Now considering the fact that triple balance occurs between the two forces already calculated and the pressure gradient force, we can deduce that:

$$\frac{u^2 \tan(\phi)}{r_A} + 2\Omega \sin(\phi) u = -\frac{1}{\rho}\frac{\partial p}{\partial y} \tag{4}$$

Where ρ is the atmospheric air density, $\partial p / \partial y$ is the vertical pressure gradient and all other variables are as previously stated. Using eq (4), we computed the pressure gradient force (per unit mass) to be $\approx$ -0.026 ms^{-2}, with the negativity of the number indicating direction.

It should be noted that throughout the paper some forces have been assigned acceleration units, this is due to the fact that we are considering everything within a non-inertial reference frame of the planet, for example, the Coriolis force (per unit mass) can also be considered using the more simplified equation:

$$F_c = -2(\mathbf{u} \times \mathbf{\Omega}) \tag{5}$$

The cross product of these two vectors yields a result with acceleration units. The value of the pressure gradient force obtained is an estimate, therefore likely differs significantly from the actual value. In order to reduce the complexity of the calculations used to model the forces producing the sandstorms, we chose to only consider the three main forces that were in triple balance, however in future papers the Navier-Stokes equations for fluid dynamics could potentially be incorporated coupled with an appropriate Python script to more precisely model the behavior of the winds causing the storms.

Conclusion

The Coriolis force exerted by Arakkis per unit mass was calculated to be approximately 0.02 ms^{-2}, from which the vertical pressure gradient force required to produce the wind speeds of the Coriolis storms was found to be $\approx$ -0.026 ms^{-2}.

References

[1] Herbert, Frank. Dune. Ace Books (1965), ISBN 9780425054710

[2] `https://dune.fandom.com/wiki/Coriolis_storm` [Accessed 4/12/24]

[3] "An Introduction to Planetary Atmospheres, by A. Sanchez-Lavega." Contemporary Physics, 52(5), ISBN 9781032918082