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Coriolis Effect: A Detailed Approach for Meaningful Learning

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A B S T R A C T

The Coriolis effect, a fundamental concept for understanding the motion of fluids over large distances in a rotating reference frame (such as our planet), is often poorly understood by students due to its abstract nature and the complexity of its visualization. This study presents a detailed, hands-on approach to teaching the Coriolis effect, aimed at fostering meaningful learning. The article begins by outlining the theoretical background and challenges associated with conventional textbook explanations, which often oversimplify the phenomenon. To address this gap, it is described an experiment carried out with a simple, low-cost, paper-based rotating disc model that enables students to visualize the apparent deflection of objects in a rotating frame of reference: to the left of the motion in the Southern Hemisphere and to the right in the Northern Hemisphere. This visual and interactive approach not only enhances conceptual understanding but also dispels common misconceptions, such as the belief that water in a sink drains in opposite directions on either side of the equator. This educational strategy can serve as an inspiration for the development of other physical, hands-on learning activities.

Keywords: Coriolis effect, rotating frame, science education, hands-on learning, meteorology

Efeito de Coriolis: uma abordagem detalhada para a aprendizagem significativa

R E S U M O

O efeito de Coriolis, um conceito fundamental para compreender o movimento dos fluidos em grandes distâncias em um referencial em rotação (como o nosso planeta), é frequentemente pouco compreendido pelos estudantes devido à sua natureza abstrata e à complexidade de sua visualização. Este estudo apresenta uma abordagem detalhada e prática para o ensino do efeito de Coriolis, com o objetivo de promover uma aprendizagem significativa. O artigo inicia com a apresentação do embasamento teórico e das dificuldades associadas às explicações tradicionais dos livros didáticos, que frequentemente simplificam demais o fenômeno. Para preencher essa lacuna, é descrito um experimento realizado com um modelo rotativo simples, de baixo custo e feito com papelão, que permite aos alunos visualizarem a deflexão aparente de objetos em um referencial em rotação: à esquerda do movimento no Hemisfério Sul e à direita no Hemisfério Norte. Essa abordagem visual e interativa não apenas amplia a compreensão conceitual, como também desfaz equívocos comuns, como a crença de que a água numa pia escoa em direções opostas nos dois lados do equador. Essa estratégia educacional pode servir de inspiração para o desenvolvimento de outras atividades em geociências e práticas de aprendizagem.

Palavras-chave: efeito de Coriolis, referencial em rotação, ensino de ciências, aprendizagem prática, meteorologia

Introduction

Have you ever considered that the atmosphere is not static, but rather rotates in concert with the Earth's surface? For instance, a cyclone over southeastern South America can persist for more than 24-hours (Jones & Simmonds, 1993; Dalanhese et al., 2023; Cardoso et al., 2025), appearing quasi-stationary relative to the continent despite the planet's rapid rotation beneath it. From the perspective of a ground-based observer, the cyclone does not "drift away" as the Earth spins; it remains embedded within the rotating gaseous envelope of the planet.

In a simplified sense, the atmosphere can be considered to have acquired the Earth's eastward rotational velocity during the planet's formation (see more details in Section “Why the Atmosphere “Follows” the Earth”). Consequently, the atmosphere and the solid Earth remain dynamically coupled through the conservation and exchange of angular momentum (Lambeck & Cazenave, 1973; Barnes et al., 1983; Rosen & Salstein, 1983; Volland, 1990, 1996; Marshall & Plumb, 2008; Holton & Hakim, 2013). Modern studies further demonstrate that exchanges of angular momentum among the atmosphere, oceans, hydrosphere, and solid Earth contribute to variations in Earth's rotational dynamics, including changes in Earth Orientation Parameters (EOPs), such as length-of-day and polar motion variability (Zhou et al., 2001; Salstein & Nastula, 2006; Dill et al., 2019; Hadi et al., 2021).

As seen by an observer on the Earth, the analysis of atmospheric motion requires adopting a reference frame fixed to the rotating planet, thereby defining a *non-inertial* frame (Taylor, 2005; Gregory, 2006; Holton & Hakim, 2013). The challenge, therefore, is to mathematically explain the air motion over a planet that is also in rotation. To accomplish this, it is necessary to describe atmospheric motion through equations that represent the three components of motion (x, y, and z). This requires a clear distinction between inertial and non-inertial reference frames, as well as an understanding of the forces acting within the atmosphere (Marshall & Plumb, 2008; Vallis, 2017).

In meteorology, atmospheric motion is described by the equations of fluid motion, such as the Navier–Stokes equations, adapted to a rotating reference frame (Holton & Hakim, 2013; Vallis, 2017; El-Nabulsi, 2018). In this framework, besides real forces (forces that arise from physical interactions between objects or fields) there are apparent (or fictitious; no interactions between objects) forces introduced into the equations to mathematically represent the air motion over a rotating surface. One of the most important, yet frequently misunderstood, of these forces is the Coriolis effect.

The Coriolis effect, also called Coriolis force, is a fundamental concept necessary for understanding large-scale motions in the atmosphere and oceans, such as global wind patterns, ocean currents, and the rotation of synoptic systems like cyclones and anticyclones (McDonald, 1952; Holton & Hakim, 2013; Vallis, 2017). Despite its importance, it remains one of the most challenging topics for students to grasp in introductory meteorology or Earth science courses. This difficulty largely stems from its abstract nature and the fact that it cannot be observed directly in everyday experiences.

The Coriolis force is not a real force, but an apparent one, arising due to the rotation of the Earth and only visible when viewed from a rotating reference frame (Persson, 1998, 2000, 2005; Phillips, 2000; Sobczak et al., 2017), making it particularly hard to internalize for learners who are not familiar with non-inertial frames.

Textbooks typically provide simplified definitions for the Coriolis effect, such as "the deflection of moving objects to the right in the Northern Hemisphere and to the left in the Southern Hemisphere" (**Figure 1**), sometimes accompanied by mathematical expressions like $f = 2\ \omega\ sin(\varphi)$, where ω is the angular velocity of the Earth's rotation and φ is the latitude. In the Southern Hemisphere, a negative sign is included in the expression to account for the direction of deflection (Aguado & Burt, 2014; Ynoue et al., 2017; Ahrens & Henson, 2019).

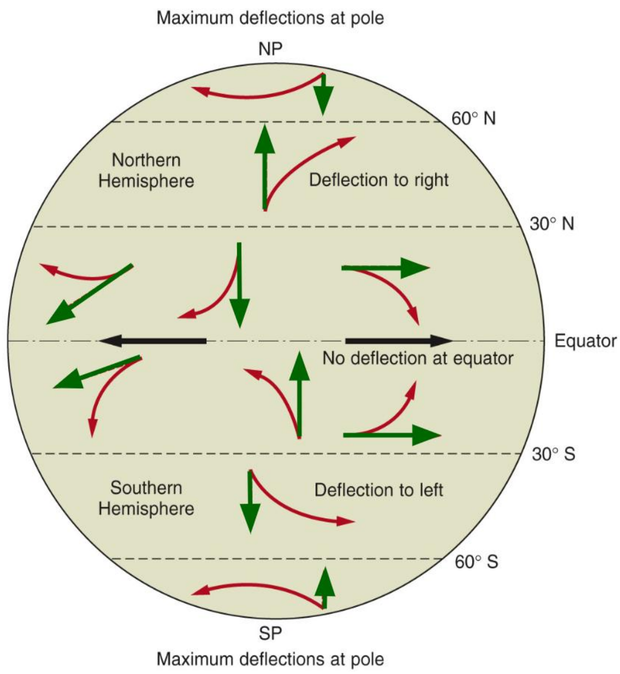

Figure 1 Coriolis effect in the Northern and Southern Hemispheres. Green arrows indicate the motion direction and red arrows indicate the deflection due to Coriolis effect.

While these descriptions are technically correct, they often fail to provide the physical intuition necessary for deep understanding. Consequently, students may memorize the rule but remain confused about its origin, implications, and physical meaning.

In response to this pedagogical challenge - and supported by studies such as Gilbert and Boulter (2000) and Lima et al. (2023), which emphasize that students construct knowledge through the development and manipulation of conceptual models (maquettes), a key element for meaningful learning - this study proposes a detailed and accessible method for teaching the Coriolis effect through a hands-on activity using simple materials.

This approach not only facilitates the visualization of deflection in a rotating system but also promotes active engagement and conceptual reflection. By connecting theoretical knowledge with concrete, experiential learning, this strategy fosters meaningful learning, in which students build new understanding based on prior knowledge and direct interaction with the subject matter.

The aim of this study is to bridge the gap between abstract theoretical derivations and an intuitive physical understanding of the Coriolis effect. We demonstrate how a low-cost rotating-disc model can be used as an active-learning tool to visualize the dynamics associated with the Coriolis effect. By providing a tangible platform for observation, we hope to enhance science education practices and encourage the development of additional pedagogical tools in meteorology and geophysical fluid dynamics.

To achieve these objectives, the following sections present: (a) the basic concepts related to the forces acting in the atmosphere; (b) a discussion of why the atmosphere follows the Earth's rotation; (c) the methodology used to conduct a practical classroom experiment, followed by a theoretical discussion and analysis of the experimental results; and, finally, the concluding remarks.

Basic Concepts

Newton's first law states that an object at rest or moving with constant velocity will remain in that state unless acted upon by a net external force (law of inertia). For a single object with constant mass and no net external force, conservation of linear momentum can be interpreted as a consequence of the law of inertia.

Newton's laws are strictly formulated for inertial reference frames (see below definition). When motion is described in a rotating reference frame, such as the Earth, Newton's laws remain applicable provided that apparent forces associated with the non-inertial frame are included. The atmosphere approximately co-rotates with the Earth due to long-term coupling with the planetary surface and the tendency of the Earth–atmosphere system to conserve angular momentum in the absence of significant external torques.

The angular momentum conservation explains only part of atmospheric motion. The atmosphere co-rotates with Earth approximately because of long-term coupling with the surface and conservation principles, but circulation patterns arise because forces create accelerations, which is described by Newton's second law.

Newton's second law states that the net external force acting on an object is equal to the rate of change of its linear momentum. Once the forces acting on the object are identified, Newton's second law, used for frames that are not accelerating or rotating (inertial reference frame), establishes that the temporal change in momentum (i.e., acceleration) is a vector whose direction is determined by the net force and whose magnitude is proportional to the net force divided by the object's mass. When motion is described in a coordinate system rotating with the Earth, Newton's second law remains applicable provided that apparent forces associated with the non-inertial reference frame, namely the centrifugal and Coriolis forces, are included (Holton & Hakim, 2013). A more detailed explanation of the reference frames and forces are presented as follow.

Inertial vs. Non-Inertial Reference Frames

In physics, the choice of a reference frame determines how we write and solve equations of motion.

Inertial Frame: A reference frame that is not accelerating or rotating (e.g., a frame fixed relative to distant stars). In this frame, Newton's second law holds in its simplest form:

$$\vec{F} = m \cdot \vec{a} \qquad \text{(eq. 1)}$$

where $\vec{F}$ is the vector force, m is mass and $\vec{a}$ is the vector acceleration represents only "real" physical forces like gravity or pressure gradients. In other words, Newton's laws are applied directly.

Considering the previous equation (eq. 1), acceleration is defined as the rate of change of velocity with time t:

$$\vec{a} = \frac{\Delta\vec{V}}{\Delta t} \quad (\text{eq. } 2)$$

where $\vec{V}$ is the vector velocity. By combining Newton's second law (eq. 1) and acceleration (eq. 2):

$$\vec{F} = m \cdot \frac{\Delta\vec{V}}{\Delta t} \quad (\text{eq. } 3)$$

If mass is constant, then the resulting eq. 3 turns:

$$\vec{F} = \frac{\Delta(m \cdot \vec{V})}{\Delta t} \quad (\text{eq. } 4)$$

where mass times velocity equals momentum.

Thus, the eq. 4 describes the change in momentum with time in an inertial framework. Rearranging the terms of eq. 4, we get a forecast equation for the velocity (wind velocity in our case):

$$\frac{\Delta\vec{V}}{\Delta t} = \frac{\vec{F}_{net}}{\text{m}} \quad (\text{eq. } 5)$$

The subscript *net* means that more than one force can be acting on the body, and it is necessary to consider the vector sum of all forces (Stull, 2017).

Non-Inertial Frame: A frame that is accelerating or rotating, such as the Earth's surface. A motion that appears to be inertial motion to an observer in non-inertial reference frame is really accelerated motion. Because the Earth spins, any point on its surface is constantly changing direction (centripetal acceleration). To apply Newton's laws in this reference frame, the acceleration of the coordinate system must be taken into account. For this reason, we must introduce "fictitious or apparent forces" in the statement of Newton's second law to account for the frame's rotation (Holton & Hakim, 2013). In this context, the centrifugal and Coriolis forces are included in the equations of motion (Gallagher & Saint-Raymond, 2007; Holton & Hakim, 2013; Loper, 2017; Ilisie, 2020; Morino, 2021; Musehane, 2021).

To transform the equations of motion from an inertial frame to a rotating Earth-fixed frame, the total acceleration is modified. The relationship between the change of a vector $\vec{V}$ in an inertial frame $(D/Dt)_{in}$ and a rotating frame $(D/Dt)_{rot}$ is:

$$\left(\frac{D\vec{V}}{Dt}\right)_{in} = \left(\frac{D\vec{V}}{Dt}\right)_{rot} + \vec{\Omega} \times \vec{V} \quad (\text{eq. } 6)$$

where $\vec{\Omega}$ is the Earth's angular velocity. For velocity vector $\vec{V}$, this leads to the equation of motion used in meteorology:

$$\frac{D\vec{V}}{Dt} = -\frac{1}{\rho}\vec{\nabla}p + \vec{g} - 2\vec{\Omega} \times \vec{V} + \vec{F_r} \quad (\text{eq. } 7)$$

here, $(-\frac{1}{\rho}\vec{\nabla}p)$ is the pressure-gradient force, g is "effective gravity", which combines Newtonian gravitational acceleration and centrifugal acceleration, $-2\vec{\Omega} \times \vec{V}$ is the Coriolis force, and $\vec{F_r}$ is frictional force (Holton & Hakim, 2013; Vallis, 2017; Cline, 2018).

Note that the equation is describing the change in momentum with time (air motion) and it is a response of the sum of different forces, including the "apparent forces". These forces are described in the next subsection.

Forces Governing Atmospheric Motion

Atmospheric motion is governed by the balance among several fundamental forces acting on air parcels within the rotating reference frame of the Earth (eq. 7). These forces determine the acceleration, direction, and organization of atmospheric flows across a wide range of spatial and temporal scales. The principal forces on the "horizontal" (including no-and-apparent forces) are the pressure-gradient force $(-\frac{1}{\rho}\vec{\nabla}p)$, centrifugal force (rewritten in the equation 7 as effective gravity, $\vec{g}$), Coriolis force $(-2\vec{\Omega} \times \vec{V})$ and frictional (or viscous) forces $(\vec{F_r})$ (Stull, 2017). Their interaction explains the existence of major atmospheric circulation systems, including Hadley cells, trade winds, jet streams, cyclones, and anticyclones (Vallis, 2017; Gróf, 2021).

Pressure-Gradient Force: The horizontal pressure-gradient force (PGF) arises from spatial differences in atmospheric pressure and acts from regions of higher pressure toward regions of lower pressure. Physically, it represents the force per unit mass generated by pressure variations within the atmosphere and constitutes the primary mechanism responsible for initiating atmospheric motion and generating winds (Wallace & Hobbs, 2006; Holton & Hakim, 2013). In vector form, the pressure-gradient force is proportional to the negative gradient of pressure and inversely proportional to air density.

In the absence of other forces, air parcels would accelerate directly across isobars from high-pressure regions toward low-pressure regions. The pressure-gradient force drives atmospheric circulations across multiple spatial scales, including land–sea breezes, mountain–valley circulations, monsoons, and trade winds (Stull, 2017; Wallace & Hobbs, 2006). Its magnitude increases when pressure changes rapidly over short distances, leading to stronger winds in regions with tightly packed isobars (Holton & Hakim, 2013).

Centrifugal Force: The centrifugal force is an apparent (fictitious) outward-directed force that appears only when motion is analyzed in a rotating or curved reference frame. It has the same magnitude as the centripetal acceleration term (real force) but points outward.

The Earth rotates around its axis, causing objects at the surface, including the atmosphere, to move along circular paths around the rotation axis. Motion along a curved path requires a continuous change in the direction of velocity, even when speed remains constant. According to Newton's second law, this change in velocity requires an acceleration directed toward the center of curvature, called centripetal acceleration. The force producing this acceleration is called the centripetal force.

A simple example is a ball attached to a string and rotated in a circle. An observer outside the rotating system sees the ball continuously changing direction and recognizes that the tension in the string provides the inward force needed to maintain circular motion. If the string were released, the ball would move tangentially to the circular path due to inertia rather than continuing to rotate. Now consider an observer rotating together with the ball. From this rotating perspective, the ball appears stationary even though the string continues pulling inward. To apply Newton's laws in this rotating (non-inertial) reference frame, an additional apparent force must be introduced to balance the inward tension. This apparent outward-directed force is called the centrifugal force.

The same principle applies to the Earth–atmosphere system. Because the Earth rotates, atmospheric motions are commonly described using an Earth-fixed rotating reference frame. In this framework, centrifugal force appears as an outward-directed apparent force acting away from the Earth's rotation axis (Holton & Hakim, 2013; Vallis, 2017). While gravity pulls air parcels toward the Earth's center, centrifugal force acts in the opposite sense relative to the rotation axis, slightly reducing the net downward acceleration experienced at the surface. For this reason, atmospheric dynamics commonly defines an effective gravity, combining true gravitational acceleration and centrifugal acceleration:

$$\vec{g}_{eff} = \vec{g} - \vec{a}_{cf} \quad (\text{eq. } 8)$$

where $\vec{g}$ is the true gravitational acceleration, $\vec{a}_{cf}$ is the centrifugal acceleration and $\vec{g}_{eff}$ is the effective gravitational acceleration used in atmospheric equations (Holton & Hakim, 2013; Vallis, 2017; Cline, 2018). This simplification is appropriate because atmospheric motions respond to the net acceleration acting on air parcels.

Centrifugal effects also become important in strongly curved atmospheric flows. In tornadoes, tropical cyclones, or highly curved jet streams, centrifugal acceleration contributes to the radial force balance together with pressure-gradient and Coriolis forces (it is a way to represent mathematically the motion). When centrifugal acceleration balances the pressure-gradient force, the flow is cyclostrophic; when centrifugal and Coriolis effects both contribute significantly, the balance is referred to as gradient-wind balance (Stull, 2017; Holton & Hakim, 2013).

Coriolis Force: This is an apparent (fictitious) force introduced into the equations of motion when the reference frame is rotating. It can be interpreted as a mathematical adjustment that accounts for atmospheric motion observed from the rotating Earth.

The Coriolis force acts perpendicular to the direction of motion of an air parcel. Its magnitude depends on the parcel velocity, the Earth's angular velocity, and latitude. Mathematically, the Coriolis acceleration is proportional to the Coriolis parameter, which varies with latitude and becomes zero at the Equator and maximum at the poles (Wallace & Hobbs, 2006).

A commonly stated consequence of the Coriolis effect is that moving air is deflected to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. More precisely, the Coriolis force changes the direction of motion relative to the Earth's surface without directly changing the wind speed. Because of this deflection, atmospheric flow does not move directly from regions of high pressure toward low pressure. Instead, at large spatial scales and away from the influence of surface friction, the Coriolis force can balance the pressure-gradient force, producing geostrophic flow in which winds move approximately parallel to isobars (Holton & Hakim, 2013).

The importance of the Coriolis force increases with spatial scale and latitude. Near the Equator, its effect is weak because the Coriolis parameter approaches zero, while at middle and high latitudes it becomes fundamental for atmospheric dynamics. Additional discussion of Coriolis effect will be provided in Section "Results and Discussion".

Frictional and Viscous Forces: Frictional and viscous forces arise from the internal resistance of air to deformation and from drag exerted by the Earth's surface. These forces oppose atmospheric motion and act to dissipate kinetic energy into heat through molecular viscosity and turbulent mixing (Holton & Hakim, 2013; Vallis, 2017). In the atmospheric equations of motion, frictional effects are represented by viscous and turbulent diffusion terms.

Near the Earth's surface, friction reduces wind speed and consequently weakens the Coriolis force, since the Coriolis acceleration is proportional to wind velocity. As a result, air parcels are able to cross isobars toward regions of lower pressure rather than flowing strictly parallel to them. This process promotes low-level convergence into cyclones and divergence from anticyclones (Wallace & Hobbs, 2006; Ahrens & Henson, 2019). Frictional influences are strongest within the atmospheric boundary layer, where the interaction between the atmosphere and the Earth's surface is most intense.

At smaller spatial scales, viscous and turbulent processes contribute to the damping of turbulence and the redistribution of momentum within the atmosphere. Although molecular viscosity is generally weak because of the low density of air, turbulent eddies generated by surface roughness, convection, and wind shear produce effective frictional mixing that strongly influences atmospheric circulation and boundary-layer structure (Stull, 1988; Vallis, 2017).

Why the Atmosphere "Follows" the Earth

Although the atmosphere is a fluid and is not physically attached to the Earth, it rotates together with the planet rather than being "left behind" as the Earth spins at speeds exceeding 1,600 km h^{-1} at the Equator. This behavior results primarily from frictional coupling with the Earth's surface and from the conservation of angular momentum.

The lowest portion of the atmosphere, known as the planetary boundary layer, is directly influenced by surface friction. Through turbulent mixing and viscosity, momentum is transferred vertically from the surface to higher atmospheric layers, coupling much of the atmosphere to the Earth's rotation (Peixoto & Oort, 1992; Vallis, 2017). As a consequence, the atmosphere acquires nearly the same mean angular velocity as the planet.

From an inertial reference frame, the atmosphere already possessed the Earth's eastward rotational velocity when it formed together with the planet. More formally, the atmosphere shares the Earth's angular momentum because it originated from the same rotating planetary system and remains dynamically coupled to the Earth through frictional and gravitational interactions. In the absence of a sufficiently strong external torque, air parcels tend to conserve their angular momentum. Consequently, the atmosphere continues rotating with the Earth rather than remaining stationary in space while the planet rotates beneath it (Holton & Hakim, 2013).

This explains why an observer sees a cyclone over southern South America as quasi-stationary or moving relative to the ground according to its characteristics, rather than appearing and disappearing due to the Earth's 24-hour rotation beneath the atmosphere.

The conservation of angular momentum is fundamental for understanding large-scale atmospheric circulation. The axial angular momentum of an air parcel can be approximated by:

$$M = (\Omega a \cos\phi + u) a \cos\phi \quad \text{(eq. 9)}$$

where M is the axial angular momentum per unit mass, Ω is the Earth's angular velocity, a is the Earth's radius, ϕ is latitude, and u is the zonal wind velocity.

But how do we connect this concept with the Coriolis effect? Because the atmosphere rotates together with the Earth, atmospheric motions are described in a rotating reference frame fixed to the planet rather than from an inertial frame in space. The adoption of this rotating reference frame introduces apparent forces into the equations of motion since the moving air parcels experience apparent accelerations associated with the Earth's rotation, including the Coriolis effect.

Consequently, whenever air moves relative to the Earth's surface (whether poleward, equatorward, eastward, or westward) its trajectory is deflected by the Coriolis force. This deflection does not generate motion itself; rather, it modifies the direction of motion produced by other forces, especially the pressure-gradient force. As a result, large-scale atmospheric flows tend to curve rather than move in straight lines; it is the way to represent the motion of trade winds, jet streams, cyclones, anticyclones etc. (Holton & Hakim, 2013; Vallis, 2017).

Note that the Coriolis effect is not an independent physical mechanism acting on the atmosphere, but rather a mathematical consequence of describing atmospheric motion relative to the rotating Earth (an artifact to describe the direction of the air movement).

Let's analyse the case of the subtropical jet. When air moves poleward from tropical regions in the upper branch of the Hadley circulation, its distance from the Earth's rotation axis decreases. Because angular momentum tends to be conserved, the air acquires increasingly strong eastward (westerly) velocities relative to the Earth's surface. Note that the displacement of the air in the Hadley Cell is primarily meridional; however, the Coriolis effect organizes the flow into predominantly westerly winds. Together, these processes contribute to the formation of the subtropical jet stream in the upper troposphere around 25°–35° latitude (Held & Hou, 1980; Holton & Hakim, 2013). In other words, angular momentum conservation and the Coriolis effect provide the physical and mathematical framework used to represent and explain this atmospheric phenomenon.

Although this discussion may appear repetitive, emphasizing this point is essential from a pedagogical perspective. Students are usually able to visualize atmospheric phenomena such as cyclones, trade winds, or jet streams; however, they often struggle to understand how these physical processes are translated into mathematical form. The main difficulty is not the phenomenon itself, but the connection between the observed atmospheric behavior and its mathematical representation.

In meteorology, equations are not created arbitrarily. They are derived from fundamental physical laws, combined with observations and theoretical assumptions, to describe and predict atmospheric motion. Thus, concepts such as the Coriolis effect should be understood not as "mysterious forces," but as mathematical tools that allow scientists to represent motion within the Earth's rotating reference frame. **Figure 2** summarizes the main ideas of this section.

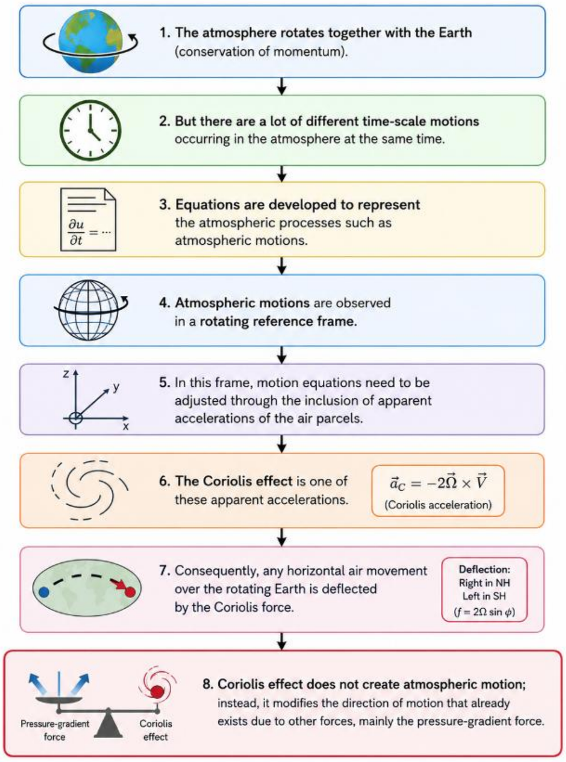

Figure 2 Summarizing the section.

Methodology

To promote a meaningful understanding of the Coriolis effect, we carry out a hands-on activity in which students build a simple paper-based model of a rotating surface (**Figure 3**). The materials needed are cardboard, a pen, a pin, a ruler, and scissors. You may also print circular maps, such as those available from Trop-ICSU

(2017), although this is optional. Additionally, having a globe available for reference can be helpful.

First, construct an open-top box using cardboard. Then, on a separate piece of cardboard, draw and cut out a circle (disk) to serve as the rotating surface. This disk should be mounted in the center of the box using a pin, allowing it to rotate freely. On top of the disk, place a circular map, ideally centered on either the North or South Pole. Use the walls of the box to attach a ruler in a fixed position above the rotating surface (**Figure 3**). This setup will help simulate a straight trajectory, making it easier to visualize the apparent deflection caused by the Coriolis effect.

Now, let's perform the activity. When the disk (map) is rotated and an observer attempts to draw a straight line from one point to another following the fixed ruler, the resulting trajectory appears curved relative to the rotating frame, visually demonstrating the Coriolis effect in action (**Figure 4**). This simple setup will be discussed in detail in the next section to clarify the Coriolis effect.

Results and discussion

A Little More about the Coriolis Effect

Our planet Earth rotates from west to east. Because of this rotation, the sun always rises in the east and sets in the west. If an observer were in space (not fixed to the Earth's surface), they would see the planet rotating counterclockwise when viewed from above the North Pole, and clockwise when viewed from above the South Pole (**Figure 5**).

Figure 3 A paper-based model of a rotating surface is being constructed. A cardboard disk is fixed with a pin to the box, and a ruler is also secured to both sides of the box.

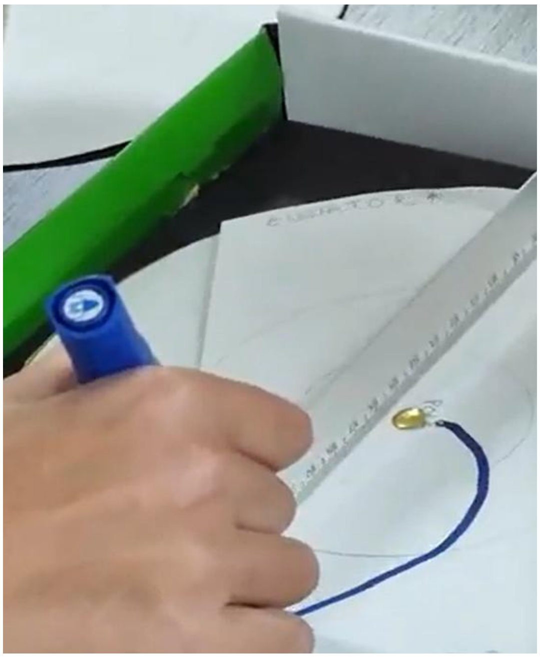

Figure 4 Curved trajectory on the rotating disk. When the disk is rotating, and we attempt to draw a straight line following the ruler, the resulting line appears curved. Details about the direction of rotation are provided in the next sections.

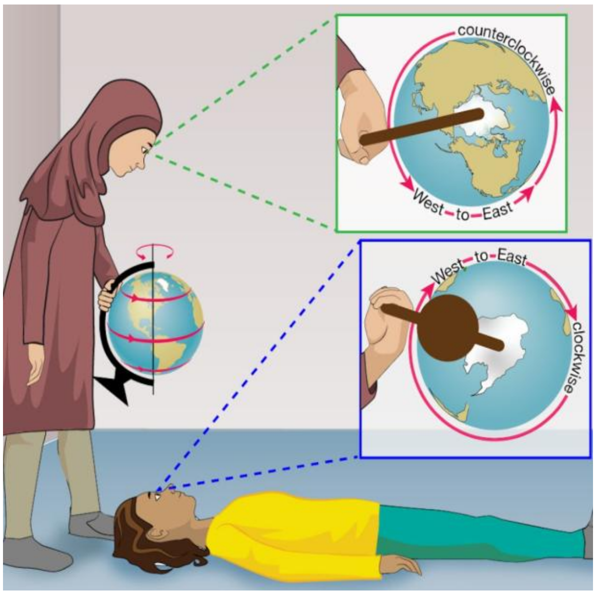

Figure 5 An observer in space would see the planet rotating counterclockwise when viewed from above the North Pole, and clockwise when viewed from above the South Pole. Adapted from Earth & Space Science (2025).

If you think about the circles formed by lines of latitude, the area of these circles decreases from the equator toward the poles (**Figure 6a**). This decrease in area is an important detail: since Earth takes 24 hours to complete one full rotation, locations closer to the equator (larger circles) have to move faster than those near the poles (smaller circles) so that all points complete the rotation in the same time. To visualize this difference in rotational speed, think of an old record player spinning a disc: an object placed near the center of the disc (representing the pole) moves slower than one placed at the edge (representing the equator), even though they both complete a full circle at the same time. Now, represent the latitudes on a flat surface (plan) for better understanding (**Figure 6b**).

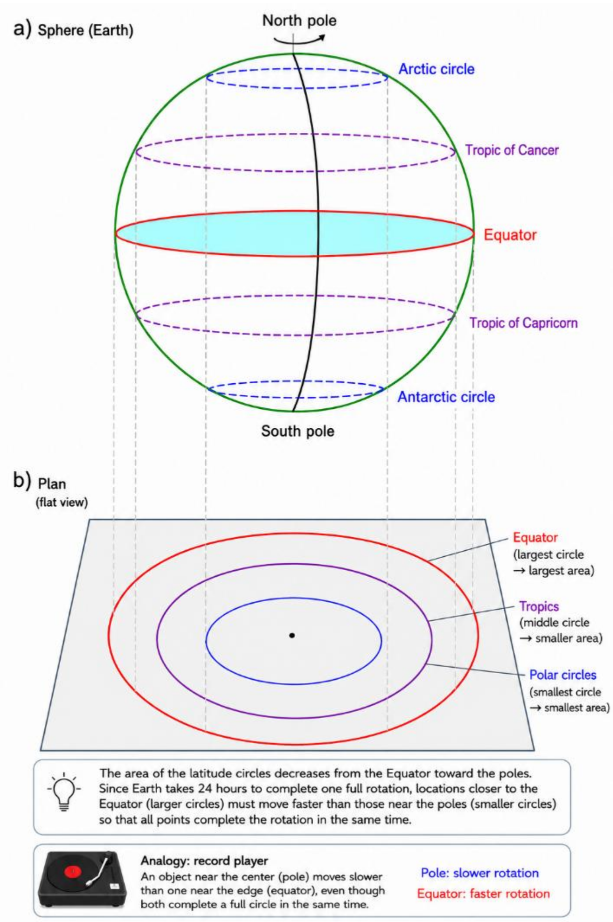

Figure 6 a) The area of the latitude bands decreases from the Equator towards the poles. b) The area of the latitude bands viewed on a plan and indication that the rotation is faster in equatorial regions than in the polar ones.

Let’s now imagine some situations:

(a) If you're standing at an open place (like a garden) and throw a small ball straight up, the ball spends very little time in the air, so Earth's rotation doesn’t significantly affect where it lands - it falls back into your hand. But if an object is launched to about 5 km in height, it spends much more time in the air. During this time, the Earth rotates underneath, meaning the object will not fall exactly where it was launched. No force actively pushes the object sideways; this displacement happens because the object is no longer fixed to the Earth's rotating surface.

(b) Consider the Southern Hemisphere. An airplane takes off from the South Pole and flies in a straight line toward the equator, intending to reach a specific point on the equator. Because the trip is not instantaneous, the Earth rotates from west to east beneath the plane; in addition, equatorial latitudes have faster rotation than the polar ones (**Figure 7**). As a result, the airplane will arrive west of its intended destination, meaning it appears to deviate to the left of its path of motion. This is easy to visualize if you look at a globe. However, remember that this deviation is only observed by an observer on the rotating Earth. An observer in space, who is outside the rotating frame of reference, would simply see the airplane follow a straight path with no deviation.

(c) Imagine an airplane taking off from the equator and flying toward the South Pole, aiming to reach a straight-line destination. At first, you might think that since the Earth rotates from west to east, the airplane would end up to the left of its intended destination. That's incorrect! Here's why:

The Earth's rotational speed is much faster at the equator than at the poles (**Figure 6**). As the airplane leaves the equator, where the surface is rotating quickly, and heads toward the South Pole, where the surface rotates much more slowly, the airplane will reach a point leftward of its take off (an apparent deflection for the observer on the planet's surface). In the Southern Hemisphere, this relative eastward displacement manifests as an apparent deflection to the left of its trajectory, consistent with the Coriolis effect. If both cases (b and c) happen in the Northern Hemisphere, the airplane would appear to drift to the right in both situations (considering the direction from the point of departure).
This apparent deviation caused by Earth's rotation is called the Coriolis effect (or Coriolis force). This effect also influences air masses moving above the Earth's surface and is essential in the equations that describe atmospheric motion.

Figure 7 An airplane departing from the South Pole is flying in a straight line, aiming to reach the equatorial latitude indicated by the green line. However, as the Earth rotates beneath the airplane, it appears to be deflected to the left relative to the Earth's surface (white curve). Adapted from The COMET Program (s/d).

Based on the previous explanation, you can see that the Coriolis effect does not influence objects with short displacements. So do not fall for the common myth that water in a sink drains in opposite directions on either side of the equator due to the Coriolis effect (Stansfield, 2009).

Visualizing the Coriolis Effect Through a Hands-On Activity

If you have reached this section and still feel confused, that is completely normal. The Coriolis effect is one of the most challenging concepts to explain in a classroom setting. However, let us try to visualize it further using the images from the hands-on activity shown in **Figure 8** (for Northern Hemisphere see **Figure 9**). You can also watch the video created for this example, available on the Itajubita Science channel (2025).

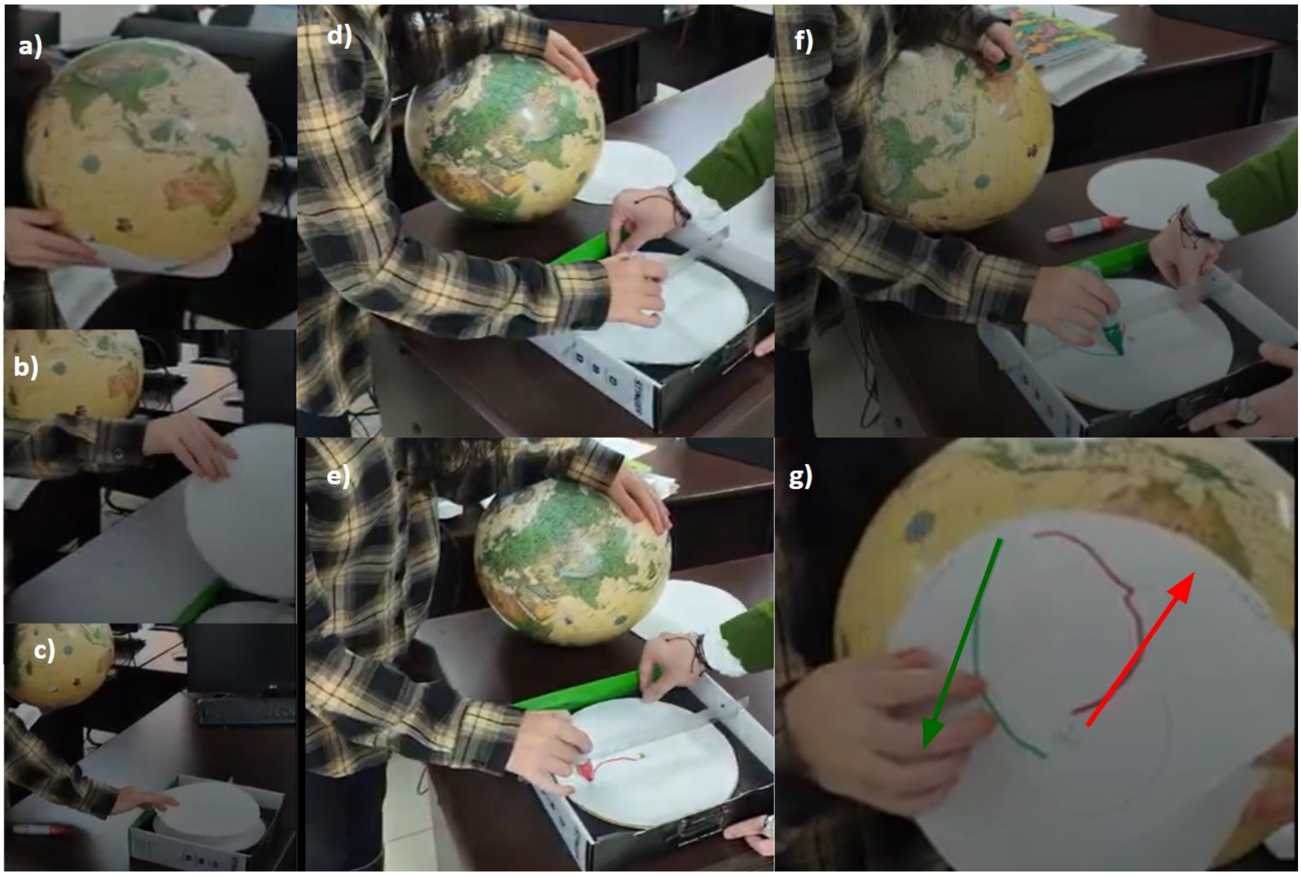

Figure 8 Hands-on activity for visualizing the Coriolis effect from the perspective of the Southern Hemisphere. In (g), the arrows indicate the trajectory as viewed from space, while the curves represent the trajectory for an observer fixed to the Earth's surface. The green (red) arrow indicates the movement from the equator (pole) to the pole (equator). See the text for details.

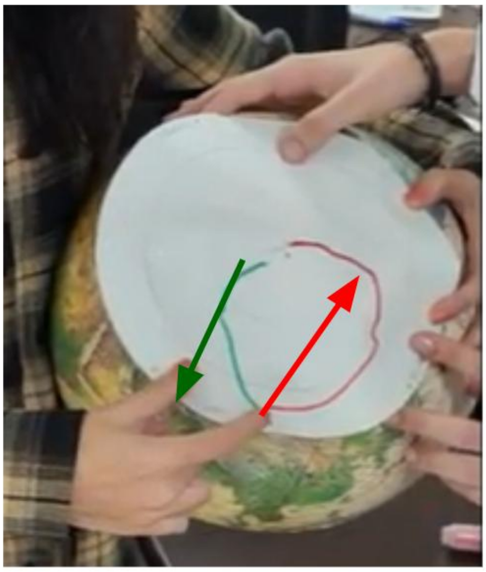

Figure 9 Hands-on activity for visualizing the Coriolis effect from the perspective of the Northern Hemisphere. The green (red) arrow indicates the movement from the pole (equator) to the equator (pole).

We have a paper disc (map) initially placed on Earth's surface (on the globe). This disc has latitude bands and the pole marked on it. Let's focus on the Southern Hemisphere (**Figure 8a**). Remove the paper disc (representing part of the southern half of the globe) - **Figure 8b** - and place it on a flat rotating device (**Figure 8c,d**). A central pin marks the South Pole - picture this like an old vinyl record. Place a ruler across the center of the disc to indicate a straight path (but the ruler cannot be in contact with the rotating surface)

Now suppose an airplane is flying from the South Pole toward the equator (where the rotation is faster), following the straight path indicated by the ruler. As the disc rotates clockwise and a red pen traces the line, you can see the resulting mark curves to the left of the airplane's path (**Figure 8e**). It is the Coriolis effect for an observer on the planet's surface.

Let's consider the opposite displacement: the airplane is flying from the equator toward the South Pole (where the rotation is slower). The Earth's rotation is clockwise. Again, the mark (in green) on the rotating disc curves to the left of the path (**Figure 8f**). So, we can conclude that the Coriolis effect in the Southern Hemisphere deflects the trajectory of objects to the left of their motion. It can be easily seen when the paper disc is put back onto the globe (**Figure 8g**). The marks on the disc show that, in the Southern Hemisphere, the deviation is always to the left of the motion, regardless of whether the object is moving toward or away from the equator.

The same experiment was also performed for the Northern Hemisphere, and the final result is shown in **Figure 9**. Note that the deviation is always to the right of the motion.

Final Remarks

For an observer in space, the trajectory shown in the experiments is a straight line. However, for an observer on the planet's surface, the trajectory is deflected to the left of the motion in the Southern Hemisphere and to the right in the Northern Hemisphere, since the Earth is a rotating reference frame. This deflection is represented mathematically in the equation of motion through the Coriolis effect. Without accounting for the Coriolis effect, it would be impossible to accurately describe or model global wind patterns and weather systems. Therefore, this concept is fundamental not only to meteorology, but also to oceanography, environmental sciences, aviation, and navigation.

Despite its relevance, the Coriolis effect remains a difficult topic for students, particularly because it requires understanding abstract ideas such as rotating frames of reference and apparent forces. Traditional teaching methods often fall short in conveying this complexity, which can lead to rote memorization rather than genuine understanding.

This article proposes the use of a hands-on conceptual model, a low-cost rotating disc, to help students visualize and physically interact with the phenomenon. Such conceptual tools are essential for promoting meaningful learning, as they allow learners to connect theoretical concepts with observable outcomes. By constructing and manipulating the model, students move beyond passive reception of information and engage in active exploration, which fosters deeper cognitive processing.

Moreover, these types of activities encourage collaboration, discussion, and integration among students. As they work together to build the model, test predictions, and interpret outcomes, they not only develop scientific reasoning but also build communicative and interpersonal skills. In this way, conceptual models serve as bridges between abstract science content and collaborative, student-centered learning environments.

We therefore emphasize the importance of incorporating practical, exploratory activities into science education. When thoughtfully implemented, these strategies can make complex topics like the Coriolis effect more accessible, engaging, and memorable for students, laying a stronger foundation for their understanding of Earth system processes.

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Supplementary material. The downloadable version is available at http://bit.ly/4pn