Project Atmosphere Canada

MODULE 4

The Coriolis Effect

Teacher's guide

Canadian Meteorological and Oceanographic Society
La Société Canadienne de Météorologie et d'Océanographie

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Project Atmosphere Canada

Project Atmosphere Canada (PAC) is a collaborative initiative of Environment Canada and the Canadian Meteorological and Oceanographic Society (CMOS) directed towards teachers in the primary and secondary schools across Canada. It is designed to promote an interest in meteorology amongst young people, and to encourage and foster the teaching of the atmospheric sciences and related topics in Canada in grades K-12.

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On behalf of
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INTRODUCTION

The Earth's atmosphere and ocean exhibit numerous instances of horizontal motions along curved paths. Near-surface winds spiral into low-pressure areas and out of high-pressure areas. Ocean currents flow in huge almost circular gyres thousands of kilometres across. Other objects, including planes and boats, freely moving horizontally almost everywhere on Earth (except at the equator) turn right or left. The turning of these moving object's paths as seen from our vantage point on Earth is the **Coriolis effect**.

Why does this curved motion occur? Aren't objects that are moving 'freely" (unconstrained) in horizontal directions supposed to move in straight paths? As described by Sir Isaac Newton's First Law of Motion, an object in motion should remain in motion in a straight line, unless acted upon by an outside force. But, there is no horizontal force acting on an object moving freely across the Earth's surface to cause it to turn right or left. Yet, except at the equator, the moving object is apparently deflected. If there is no horizontal force acting to make this happen, there must be another explanation. There is! The Earth is turning underneath the moving object, that is, the Earth rotates.

All motion must be measured with respect to something, and the Earth is our frame of reference. The Earth is so immense that we usually think of it as being stationary. That is why objects moving horizontally and freely appear to turn to the right or left. Actually, it is the Earth that is doing the turning underneath as the object moves forward.

The effect of the Earth's rotation on horizontally moving objects is greatest at the poles. The Coriolis deflection decreases as latitude decreases, until it is zero at the equator. In the Northern Hemisphere, the sense of the Earth's rotation is counterclockwise as seen from above the North Pole. Consequently, moving objects always appear to turn rightward in the Northern Hemisphere. The reverse happens in the Southern Hemisphere because of the clockwise sense of our planet's rotation when looking down from above the South Pole. There, horizontally moving objects appear to turn toward the left.

Scientists account for the Coriolis effect by inventing an imaginary force called the **Coriolis force**. This Coriolis force is applied in combination with real forces such as the pressure gradient force and friction to explain motions of objects in terms of Newton's laws. The Coriolis force is defined as always acting perpendicular to the direction of motion; to the right in the Northern Hemisphere to explain rightward turning, and to the left in the Southern Hemisphere to describe leftward turning. It is all necessary because the Earth turns!

BASIC UNDERSTANDINGS

Motion

1. Motion describes the continuous change of location of an object.

2. All motion is relative, that is, motion must be measured from a frame of reference. Most of the time we use the Earth as our frame of reference, such as when we measure the speed of a car. But persons walking in a travelling airliner, ship, or train car use the airliner, ship or train as their frame of reference.

3. The term *speed* describes how fast an object is moving. Speed is the magnitude of motion. Motion can be described fully by indicating both speed and direction. Such fully described motion is called *velocity*.

4. Motion results from forces (pushes or pulls) acting on an object. Sir Isaac Newton studied motion and devised basic laws to describe his findings. His first law indicates that an object at rest tends to stay at rest and a moving object moves in a straight line at a constant speed, unless acted upon by an outside force. Another of his laws describes how an outside force can speed up or slow down the object, or it can change the direction of the object's motion.

Horizontal Motion on the Earth

5. Objects moving horizontally and freely (unconstrained and not being acted upon by an outside horizontal force) across the surface of the Earth **at the equator** follow paths that are straight relative to the Earth's surface, as described by Newton's First Law of Motion.

6. Objects moving horizontally and freely across the surface of the Earth **everywhere except at the equator** follow paths that are curved as measured from Earth. In the Northern Hemisphere, they turn towards the right of the direction of motion and in the Southern Hemisphere they turn left. This deflection is called the ***Coriolis effect,*** after Gaspard Gustave de Coriolis.

7. The observed Coriolis effect arises because the Earth is rotating, and in non-equatorial locations, is actually turning underneath as a horizontally and freely moving object travels forward. Because the motion is being measured relative to the Earth, the motion appears to be along a curved path.

8. Anywhere in the Northern Hemisphere, the sense of the Earth's rotation is counterclockwise as seen from above the North Pole. Consequently, the observed curved motion is always to the right of the direction of motion.

9. Anywhere in the Southern Hemisphere, the sense of the Earth's rotation is clockwise as seen from above the South Pole. Consequently, the observed curved motion is always to the left of the direction of motion.

10. Because there is no turning of the surface of the Earth (sense of rotation) underneath a horizontally and freely moving object at the equator, there is no curving of the object's path as measured relative to the Earth's surface. The object's path is straight, that is, there is no Coriolis effect.

11. The Earth's rotational effects on horizontally and freely moving objects are greatest at the poles; therefore, the Coriolis effect is greatest at the poles.

12. As the latitude at which horizontally and freely moving objects are located decreases, the twisting of the underlying Earth's surface due to the planet's rotation decreases. That is, the Coriolis effect decreases as the latitude decreases. It is maximum at the poles and absent at the equator.

Coriolis Force

13 The Coriolis effect arises because motion is being measured from a rotating frame of reference. There are no outside forces acting on a horizontally moving object that causes the observed curved motion.

14. Scientists have invented an imaginary force, called the *Coriolis force,* to account for the Coriolis effect. This has been done so that Newton's Laws of Motion can be applied to movements measured relative to the Earth's surface.

15. The Coriolis force is defined as always acting perpendicular to the direction of motion. Because the sense of the Earth's rotation as seen from above in the Northern Hemisphere is opposite to that in the Southern Hemisphere, it is further defined as always acting to the right in the Northern Hemisphere and always to the left in the Southern Hemisphere.

16. The Coriolis force is also defined as being directly proportional to the sine of the latitude to account for the increasing curvature of paths as latitude increases. The trigonometric function *sine* is zero at an angle of 0 degrees (equatorial latitude) and 1 (maximum) at an angle of 90 degrees (polar latitude).

Atmospheric and Oceanic Applications

17. Horizontally moving air in the Northern Hemisphere is continually pulled to the right of the direction of motion by the Coriolis force. This causes air being acted on by horizontal pressure forces to turn rightward rather than flowing directly towards lowest pressure. Around low-pressure centres, the combination of forces produce counterclockwise circulation patterns as seen from above. Around high-pressure centres, the outward flowing air is also forced rightward, producing a clockwise circulation.

18 The role of the Coriolis effect is of increasing importance as the distance over which it acts increases. The Coriolis effect is negligible in very small-scale motions such as water swirling down a drain. Broader-scale storm systems, including the wave cyclones of the mid-latitudes and hurricanes, have circulations with Coriolis force components. These systems cannot

exist at the equator and cannot cross between the Northern and Southern Hemispheres because they cannot exist without the Coriolis effect.

19. In the Southern Hemisphere, the continuous leftward pull of the Coriolis force produces clockwise circulation around low-pressure centres and counterclockwise patterns around high-pressure centres.

20. On a global scale, the Coriolis force contributes towards the maintenance of the wind belts and upper air circulations, including jet streams.

21. Surface water set in motion by the wind is deflected by the Coriolis effect, flowing to the right of the wind in the Northern Hemisphere and to the left in the Southern Hemisphere.

22. Driven by prevailing winds, large roughly circular current systems, called *gyres*, circulate clockwise as seen from above in the mid-latitude ocean basins of the Northern Hemisphere and counter-clockwise in the Southern Hemisphere.

23. Moving surface water acts on water below, which is further deflected by the Coriolis effect. That water acts on the water below it, which is deflected even more. The overall result is that the net transport of water over the wind-driven column is 90 degrees to the right of the wind direction in the Northern Hemisphere and to the left in the Southern Hemisphere. This is called **Ekman transport**.

24. Winds blowing parallel to coasts can transport surface water towards or away from the shore, depending on wind direction, coastal orientation, and hemisphere (which determines the direction the Coriolis force acts). Where winds move surface water away from shore, cold water rises to the surface. This process is called *upwelling*.

25. In estuaries, the Coriolis effect tends to swing the incoming tidal flow and the seaward flowing river water to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. This results in a higher concentration of inflowing seawater on one side of the estuary and fresh river water outflow on the other side.