Impact of Climate Change on Earth's Rotational Dynamics

For Prelims: Shift in Earth's Axis, Climate change, Leap second, Precession, Summer solstice, Winter solstice, vernal equinox

For Mains: Earth's Rotation and Climate Change, Important Geophysical Phenomena

Source: TH

Why in News?

Recent research highlights that **melting polar ice caps due to climate change** are causing the **Earth to spin more slowly,** leading to minute changes in the duration of a day.

- This phenomenon, while not immediately noticeable in daily lives, could have significant implications for technology reliant on precise timekeeping.

How is Climate Change Affecting Earth's Rotation?

- **Melting Ice Caps:** The melting of polar ice sheets causes **water to flow towards the equator**, increasing the **Earth's oblateness and moment of inertia.**
  - Studies show that over the last two decades, the Earth's rotation has slowed by **approximately 1.3 milliseconds per century.**
    - The principle of **angular momentum** explains this effect, as polar ice melts and moves towards the equator, the **Earth's moment of inertia (mass distribution near the equator)** increases, causing its **rotational speed (velocity)** to decrease to conserve **angular momentum, resulting in a slower spin**.
    - Projections indicate that **if high emission scenarios persist,** this rate may **increase to 2.6 milliseconds per century,** making climate change a dominant factor in the Earth's rotational slowdown.
- **Axis Shifts:** The melting ice also **influences the Earth's axis of rotation,** causing a slight but **measurable shift.** This movement, while small, is another indicator of how climate change impacts fundamental Earth processes.
  - The Earth's rotational axis is tilted relative to its geographic axis. This tilt causes a phenomenon known as the **Chandler wobble, which can affect rotational timing and stability.**

Other Factors Affecting the Earth's Rotation Speed

- **Groundwater Depletion:** The loss of groundwater can also alter mass distribution, contributing to changes in rotational dynamics.
- **Torsional Waves:** Convection currents in the Earth's outer core **generate torsional waves that impact the planet's rotation**. These waves oscillate through the Earth and can correlate with changes in the length of a day.
  - **Torsional waves are oscillating movements within the Earth's outer core** that twist

or rotate around the Earth's axis, influencing the planet's rotational speed.

- **Influence of Celestial Bodies:** Earth’s rotation is influenced by the Moon and also other celestial bodies. About 1.4 billion years ago, the **Moon was much closer to Earth, resulting in significantly shorter days of just 18 hours and 41 minutes**. Today, a day is 24 hours, and it continues to **increase due to the Moon's gradual distancing.**
    - The gravitational pull of the **moon creates tidal forces that can affect the rotation of the Earth.** These tidal effects typically contribute to a gradual slowing of the planet’s rotation over time.
- **Earth's Interior Dynamics**: Movements within the **Earth’s mantle and core** can influence rotational speed. These include changes in the **tilt of the inner core or fluctuations in core density.**

What are the Implications of Slowdown of Earth's Rotation?

- **Leap Seconds:** The rotation of the Earth affects the need for **leap seconds** to synchronize **atomic clocks with solar time.**
    - A slowdown in rotation may necessitate the addition of leap seconds, impacting systems reliant on precise timekeeping.
    - This adjustment can cause issues in technology, such as **network outages or discrepancies in data timestamps.**
- **Global Positioning Systems (GPS):** GPS satellites rely on precise time measurements. Variations in Earth’s rotation can affect the **accuracy of GPS systems, potentially leading to minor errors in navigation** and location services.
- **Sea Level Rise:** The redistribution of mass from melting polar ice contributes to **changes in sea levels.** A slowdown in Earth's rotation can affect ocean currents, including the **Global Mean Ocean Circulation (GMOC),** potentially influencing regional climate patterns and exacerbating issues related to sea level rise.
    - GMOC is a large-scale system that moves water, heat, and nutrients across the world's oceans. It plays a vital role in regulating global climate by redistributing heat between regions.
- The redistribution of mass from melting polar ice contributes to **changes in sea levels**. A slowdown in Earth's rotation **can affect ocean currents and potentially influence regional climate patterns,** exacerbating issues related to sea level rise.
- **Earthquakes and Volcanic Activity:** Although less direct, changes in Earth's rotation and **mass distribution can influence tectonic processes.**
    - Variations in rotation might impact the **stress distribution in Earth's crust, potentially influencing seismic and volcanic activity.**
- **Climate Change Evidence:** This phenomenon is a stark reminder of climate change's extensive impact, **affecting not only weather patterns and sea levels** but also the very mechanics of our planet’s rotation.

What are the Motions of the Earth and Their Effects?

- **Earth’s Rotation:** The Earth rotates around its axis, which is an imaginary line running from the North Pole to the South Pole. This **rotation occurs from west to east.**
    - It takes **approximately 24 hours to complete one full rotation,** resulting in the cycle of day and night.
    - **Effects:**
        - **Precession:** It involves the **wobble in Earth's rotational axis**, altering the direction it points relative to fixed stars.
            - **Precession** affects the timing and intensity of seasons. Currently, the Northern Hemisphere experiences winter during perihelion and summer during aphelion. In about 13,000 years, **these conditions will reverse, making Northern Hemisphere winters colder and summers hotter.**
        - **Coriolis Effect:** Rotation affects wind and ocean currents, causing them to turn right in the Northern Hemisphere and left in the Southern Hemisphere due to

the **Coriolis force.**
- **Time Zones:** Different regions experience **sunrise and sunset at different times,** necessitating the establishment of time zones.
- **Circle of Illumination:** The boundary **line dividing the day and night sides** of the Earth is known as the circle of illumination.

- **Revolution of the Earth:** Earth revolves around the **Sun in 365 days, 6 hours, 9 minutes at a speed of 29.29 to 30.29 km/s.** The extra 6 hours, 9 minutes results in an additional day every four years, designated as a **leap year** with 29th February.
  - **Effects:**

- **Seasons:** The tilt of the Earth's axis relative to its orbit around the Sun results in varying angles of sunlight throughout the year, causing the four seasons: spring, summer, autumn, and winter.

- **Solstices:** The summer solstice (around 21st June) and winter solstice (around 21st December) mark the longest and shortest days of the year, respectively.

- **Equinoxes:** The vernal equinox (around 21st March) and autumnal equinox (around 23rd September) are characterised by nearly equal lengths of day and night.

- **Axial Tilt:** Earth's axis is tilted at 23.5° from the vertical, perpendicular to its orbit around the sun. This axial tilt, also known as obliquity, creates an angle of 66.5° with the orbital plane. **This tilt, combined with Earth's revolution around the sun, affects the length of days and nights** and is **crucial for the changing seasons.**

Drishti Mains Question:

Q. Discuss the implications of climate change on Earth's rotational dynamics

UPSC Civil Services Examination Previous Year Question (PYQ)

Prelims

Q. Variations in the length of daytime and nighttime from season to season are due to (2013)

(a) the earth's rotation on its axis
(b) the earth's revolution around the sun in an elliptical manner
(c) the latitudinal position of the place
(d) revolution of the earth on a tilted axis

Ans: (d)