Chapter 9 Lecture

Essentials of Oceanography
Eleventh Edition

Tides

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Chapter Overview

• Tides are the rhythmic rise and fall of sea level.
• Tides are very long and regular shallow-water waves.
• Tides are caused by gravitational attraction of the Sun, Moon, and Earth.
• Different tidal patterns exist.
What Are Tides?

- **Tides** – periodic raising and lowering of ocean sea level
- Occur daily
- **Isaac Newton’s** gravitational laws explain relationship
- Tides recognized even by early sailors
Tide-Generating Forces

- Tides caused by combination of gravity and motion between Earth, Moon, and Sun
- **Barycenter** between Moon and Earth
  - Common center of mass or balance point
  - Beneath Earth’s surface because of Earth’s greater mass
Gravitational Forces

• Gravitational force derived from Newton’s Law of Universal Gravitation
  – Every object that has mass in the universe is attracted to every other object.
Gravitational Forces

- Gravitational force proportional to product of masses
  - Increase mass, increase force
- Inversely proportional to square of separation distance

\[ F_g = \frac{G m_1 m_2}{r^2} \]
Gravitational Forces

- Greatest force at **zenith** – closest to moon
- Least force at **nadir**
  – furthest from moon and opposite zenith
Centripetal Force

• Center-seeking force
• Keeps planets in orbit via gravitational attraction
• Tethers Earth and Moon to each other
Resultant Forces

- Mathematical difference between gravitational and centripetal forces
- Relatively small
Tide-Generating Forces

• Resultant force has significant horizontal component

• Lunar bulges
  – Result when force pushes water into two simultaneous bulges
    • One toward Moon
    • One away from Moon
Idealized Tidal Bulges

- Water bulges away from Moon
- Water bulges toward Moon
- Equator
- Earth's rotation
- Average sea level

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Tidal Phenomena

• **Tidal period** – time between high tides
• **Lunar day**
  – Time between two successive overhead moons
  – 24 hours, 50 minutes
• **Solar day** – 24 hours
• **High tides are 12 hours and 25 minutes apart**
Lunar Day
Tidal Bulges – Sun’s Effect

- Similar to lunar bulges but much smaller
- Moon closer to Earth, exerts greater gravitational force
Earth’s Rotation and Tides

- **Flood tide** – water moves toward shore
- **Ebb tide** – water moves away from shore
- Tidal bulges are fixed relative to the Sun’s and Moon’s positions
  - Earth’s rotation moves different geographic locations into bulges
Monthly Tidal Cycle

- **Tidal range** – difference between high and low tides
- **Syzygy** – Moon, Earth, and Sun aligned
- **Quadrature** – Moon in first or third quarter phase
Monthly Tidal Cycle

• **Spring tides**
  – New or full moons
  – Tidal range greatest
  – Syzygy

• **Neap tides**
  – Quarter moons
  – Tidal range least
  – Quadrature
Monthly Tidal Cycle

• **New Moon** – Moon between Earth and Sun, cannot be seen from Earth
• **Full Moon** – Moon and Sun opposite
• **Quarter Moon** – Moon appears half lit
Monthly Tidal Cycle

- Other Moon phases
- **Waxing crescent** – Moon moving from new to first quarter
- **Waxing gibbous** – Moon moving from first quarter to full
- **Waning gibbous** – Moon moving from full to last quarter
- **Waning crescent** – Moon moving from last quarter to new moon
Complicating Factors

- **Declination** – Angular distance of the Moon or Sun above or below Earth’s equator
- Sun to Earth: 23.5 degrees north or south of equator
- Moon to Earth: 28.5 degrees north or south of equator
- Lunar and solar bulges shift from equator – Unequal tides
Declination and Tidal Bulges
Complicating Factors

- Elliptical orbits
- Earth around Sun:
  - Tidal range greatest at perihelion (January)
  - Tidal range least at aphelion (July)
Complicating Factors

• Moon around Earth:
  – Tidal range greatest at **perigee** (Moon closest to Earth)
  – Tidal range least at **apogee** (Moon furthest from Earth)
  – Perigee–apogee cycle is 27.5 days

• **Proxigean tides** – spring tide + perigee
  – Exceptionally high tidal range
  – Every 1.5 years or so
Effects of Elliptical Orbits
Idealized Tide Prediction

- Two high tides/two low tides per lunar day
- Six lunar hours between high and low tides
Predicted Idealized Tides
Real Tides

- Continents and friction with seafloor modify tidal bulges.
- Tides are shallow-water waves with speed determined by depth of water.
- Idealized tidal bulges cannot form.
  - Cannot keep up with Earth’s rotation
Real Tides

• Crests and troughs of tides rotate around amphidromic point.
  – No tidal range at amphidromic points
• Cotidal lines – connect simultaneous high tide points
• Tide wave rotates once in 12 hours.
Cotidal Map
Tidal Patterns

• Diurnal
  – One high tide/one low tide per day

• Semidiurnal
  – Two high tides/two low tides per day
  – Tidal range about same

• Mixed
  – Two high tides/two low tides per day
  – Tidal range different
  – Most common
Tidal Patterns
Monthly Tidal Curves
Tides in Coastal Waters

• Standing Waves
  – Tide waves reflected by coast
  – Amplification of tidal range
Tides in Coastal Waters

• Bay of Fundy in Nova Scotia
  – World’s largest tidal range
Tides in Coastal Waters

• Tidal Bores
  – Tide-generated wall of water
  – Moves up certain rivers

• Conditions needed for tidal bores
  – Large spring tidal range of at least 6 m (20 ft)
  – Abrupt flood tide and short ebb tide phases
  – Low-lying river with seaward current
  – Shallowing of landward sea floor
  – Narrowing of basin in upper reaches
Coastal Tidal Currents

- Rotary Current
  - Current that accompanies the slowly turning tide crest in a Northern Hemisphere basin
  - Rotates counterclockwise

- Reversing current
  - Alternating current
  - Moves in and out of narrow coastal passages
Coastal Tidal Currents

- **Flood current**
  - Water rushes up a bay or river with incoming tide
- **Ebb current**
  - Water drains from bay or river as tide goes out
- **High slack water**
  - Peak of each high tide with no current motion
- **Low slack water**
  - Peak of each low tide with no current motion
Coastal Tidal Currents

Typical tidal curve for a bay:

- Lunar hours: 0, 3, 6, 9, 12, 15, 18, 21, 24
- Lower high water
- Higher high water
- Higher low water
- Lower low water
- Datum (MLLW)
- HSW = high slack water (velocity = zero)
- LSW = low slack water (velocity = zero)

Velocity of ebb and flood currents based on tidal curve above:

- Ebb current (out)
- Flood current (in)
- Ebb current (out)
- Flood current (in)

Current velocity increases at HSW and LSW (velocity = zero).
Coastal Tidal Currents

• **Whirlpool**
  – Rapidly spinning seawater
  – Restricted channel connecting two basins with different tidal cycles
  – *Maelstrom* near Arctic Norway
Tides and Marine Life

- **Grunion spawning**
  - Small silvery fish
  - Come out of water in California to spawn
  - Spawn only after each night’s higher high tide has peaked on the three or four nights following the night of the highest spring high tide

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Tide-Generated Power

• Tides can be trapped one of 2 ways
  – Tidal water trapped behind coastal barriers in bays and estuaries turns electrical turbines
  – Tidal currents in narrow channels turn underwater turbines
Tide-Generated Power

• Does not produce power on demand
• Possible harmful environmental effects
• Renewable resource
• First Asian power plant in 2006
• United Kingdom proposed building world’s largest tidal power plant.
Power Plant at La Rance, France

- Successfully producing tidal power since 1967
- Potential usable tidal energy increases with increasing tidal range.
End of CHAPTER 9
Tides