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# Rhythms of the Sea: Sun, Moon & Cayman’s King Tides

From first-principles gravity and double tidal bulges to seasonal Caribbean warming, low air pressure, and basin resonance.

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PART 01 • STARTING FROM FIRST PRINCIPLES

# Tide Myths vs. Real Physics

**Myth: “Only the Moon causes tides.”** *Click to reveal the truth ▸*

## Sun & Moon Both Pull

Moon drives ~69% of tides; Sun drives ~31%.

**Myth: “High tide happens once a day.”** *Click to reveal the truth ▸*

## Two High Tides Per Lunar Day

Coasts see two peaks every 24h 50m.

**Myth: “Water piles only toward the Moon.”** *Click to reveal the truth ▸*

## Two Opposite Bulges Form

Differential gravity stretches both near and far oceans.

**Myth: “Earthquakes trigger King Tides.”** *Click to reveal the truth ▸*

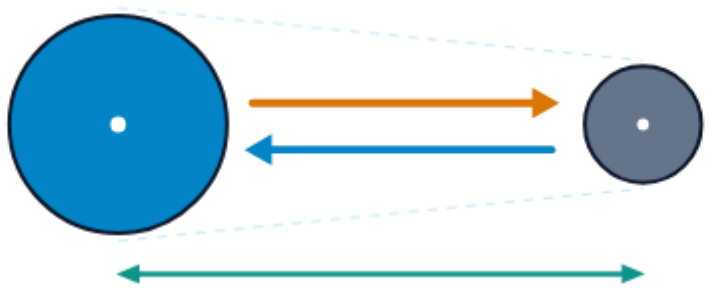
## Orbits Plus Seasonal Ocean Lift

Predictable lunar alignment amplified by warm autumn seas.

**Quick Poll: If gravity pulls water toward the Moon, why is there ALSO a high tide on Earth’s far side?**

STEP 01 • UNIVERSAL GRAVITY

# Mutual Attraction & The 1/r³ Tidal Law



Earth (Mass $M_1$) Center Distance r Moon (Mass $M_2$)

$$F_{gravity} = \frac{GM_1M_2}{r^2} \qquad \Delta F_{tidal} \propto \frac{1}{r^3}$$

## Weak Force, Cosmic Reach

Every mass attracts every other mass across space.

## Mutual Earth-Moon Pull

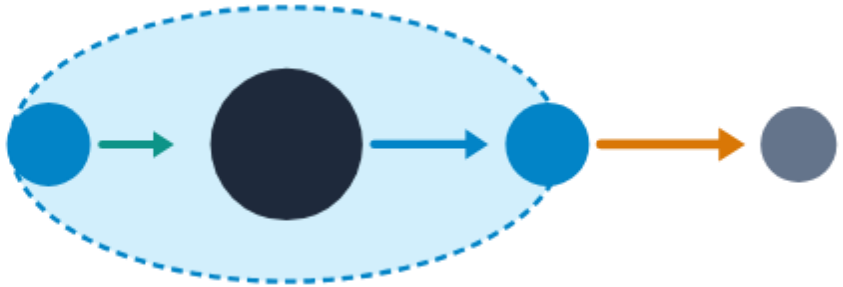
Earth holds the Moon in orbit while the Moon stretches Earth's oceans.

## Why Inverse Cube (1/r³)?

Tides measure gravity's difference across Earth—2× distance cuts tides 8×!

STEP 02 • DIFFERENTIAL ACCELERATION

# Why Gravity Creates Two Opposite Bulges



Far Water: 1 Step (Left Behind) Solid Earth: 2 Steps Near Water: 3 Steps (Pulls Ahead)

### 1. Free-Fall Toward the Moon

Near water, solid Earth, and far water all accelerate toward the Moon.

### 2. Near Bulge Pulls Ahead

Strongest gravity pulls near-side water ahead of the solid Earth.

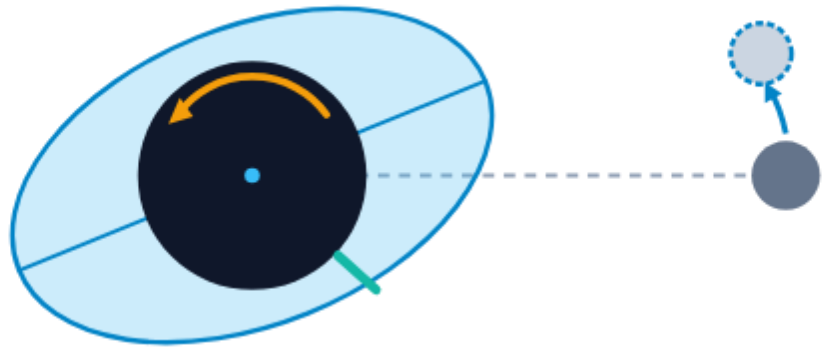
### 3. Far Bulge Lags Behind

Solid Earth pulls away from the weaker-pulled ocean on the far side.

**Class Demo (Falling Pool Balls): Near water takes 3 giant steps, Earth takes 2 medium steps, Far water takes 1 baby step!**

STEP 03 • TOP-DOWN ROTATION & ORBITAL LAG

# 24h Spin, Friction Drag & The 50-Min Shift



North Pole Top-Down View  Spin Drags Bulge Ahead  Moon Moves +12.2° (+50 min)

### Two Bulges Per Rotation

Earth spins under both tidal bulges every 24 hours.

### 24h 50m Lunar Day

Earth turns an extra ~50 minutes daily to catch the orbiting Moon.

### Seabed Friction Lead

Ocean-floor friction drags the bulge slightly ahead of the Moon.

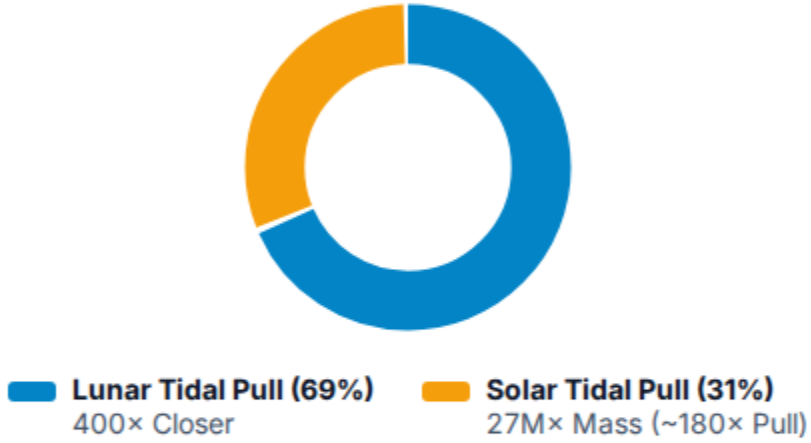
**Class Demo (Ring of Water): Spin Grand Cayman 360° while the Moon takes one step forward!**

PART 02 • WHY SOME TIDES ARE BIGGER THAN OTHERS

# Giant Mass vs. Vast Distance

## Lunar vs. Solar Tidal Force Share

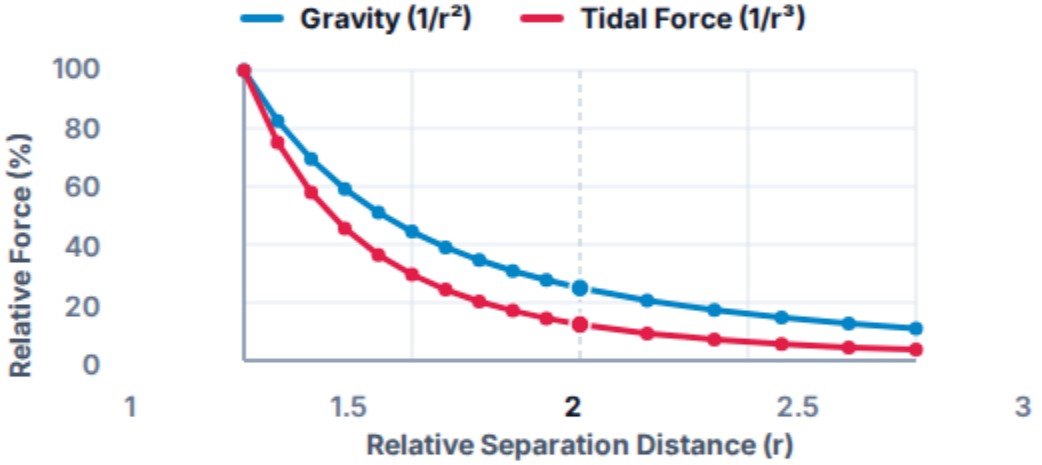
PROPORTIONAL TIDE-GENERATING CONTRIBUTION




**Key Takeaway:** Although the Sun is **27 million times** more massive than the Moon, it is **400 times** farther away. Under the $1/r^3$ tidal law, distance cubes to $400^3$ = 64 million, leaving the Sun with only **31%** of Earth's tidal pull vs. the Moon's **69%**.

## Gravity ($1/r^2$) vs. Tidal Gradient ($1/r^3$) Decay

RELATIVE FORCE STRENGTH VS. SEPARATION DISTANCE




**Key Takeaway:** Doubling the distance between two bodies weakens standard gravity to **25%** ($1/2^2$), but slashes tide-generating differential force down to **12.5%** ($1/2^3$)—explaining why modest orbital distance changes strongly alter tide height.

**Scale Factoid: The Moon-to-Sun mass ratio (1 : 27,000,000) equals one penny (2.5 g) to a Cayman Airways 737 (~67.5 tonnes)!**

SEVERITY FACTOR 01 • SOLAR–LUNAR ALIGNMENT

# 1/7 • Spring Alignment vs. Neap Cancellation

## Spring Tide (0° or 180°)



Sun and Moon pull along one axis (+31% solar boost).

## Neap Tide (90° Right Angle)



Perpendicular pulls partially cancel into mild tides.

**Class Demo (Tug-of-War): Pull Ocean in a straight line (Spring), then move Sun 90° aside (Neap)!**

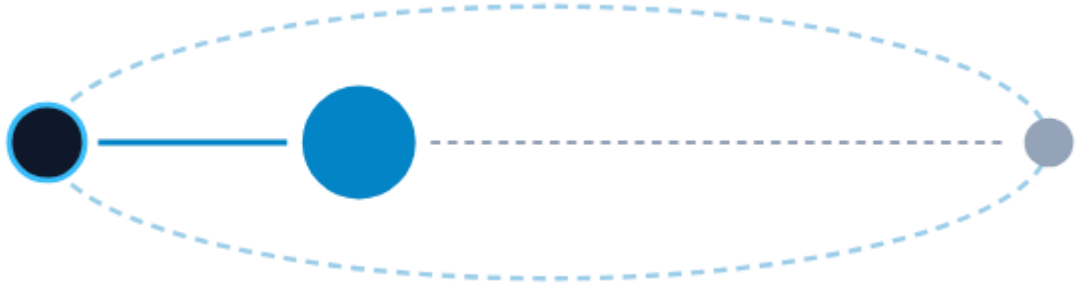
TIDE SEVERITY • 1 / 7

7. Storm Surge
6. Low Air Pressure
5. Current Setup
4. Thermal Expansion
3. Solar Perihelion
2. Lunar Perigee
1. Spring Alignment ✓

Spring Baseline

SEVERITY FACTOR 02 • ELLIPTICAL LUNAR ORBIT

# 2/7 • Lunar Perigee (“Supermoon”) = King Tide



**Perigee: 356,500 km (Close)** | **14% Closer → +15–20% Lunar Pull** | **Apogee: 406,700 km (Far)**

## Why Supermoons Matter

Inverse-cube scaling ($1/r^3$) amplifies small orbital distance drops.

## Perigean Spring = King Tide

New or Full Moon at perigee creates seasonal King Tides.

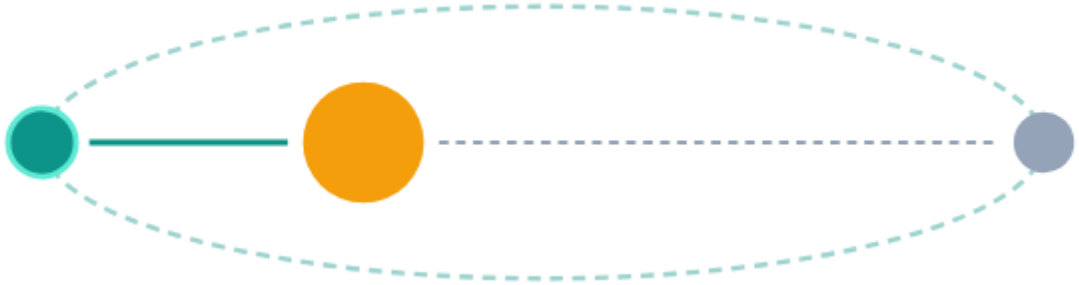
TIDE SEVERITY • 2 / 7

7. Storm Surge
6. Low Air Pressure
5. Current Setup
4. Thermal Expansion
3. Solar Perihelion
2. Lunar Perigee ✓
1. Spring Alignment ✓

King Tide Active

SEVERITY FACTOR 03 • ELLIPTICAL EARTH ORBIT (WINTER)

# 3/7 • Winter Perihelion = Proxigean Spring Tide



Perihelion: 147.1M km (Jan)

5M km Closer → +10% Solar Pull

Aphelion: 152.1M km (Jul)

## Winter Solar Boost (+10%)

Earth swings 3.3% closer to the Sun each January.

## Proxigean Spring Tide

Maximum astronomical tide when Spring, Perigee, and Perihelion align.

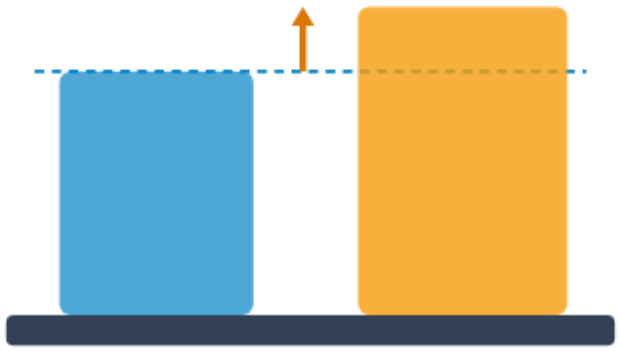
TIDE SEVERITY • 3 / 7

7. Storm Surge
6. Low Air Pressure
5. Current Setup
4. Thermal Expansion
3. Solar Perihelion ✓
2. Lunar Perigee ✓
1. Spring Alignment ✓

Proxigean Ceiling

SEVERITY FACTOR 04 • SEASONAL SEA TEMPERATURE (SEP–NOV)

# 4/7 • Thermal Expansion Lifts Warm Seas



Feb–Mar: 26–27°C  +10 to 14 cm Lift  Sep–Nov: 29–30°C

## 3 °C Seasonal Warming

Late-summer heating warms Cayman's upper ~200 m water column.

## Lower Density = Vertical Expansion

Density drops from 1,023.5 to 1,022.3 kg/m³, expanding upward before tides act.

**Steric Expansion Formula (Fixed Seafloor):** $\Delta h = \alpha \cdot H \cdot \Delta T \approx 12.4\ \text{cm}$

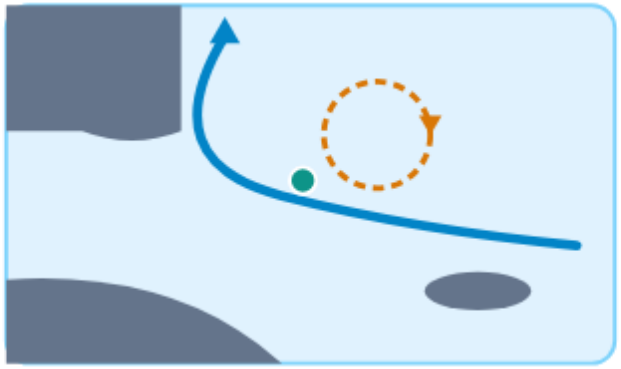
TIDE SEVERITY • 4 / 7

7. Storm Surge
6. Low Air Pressure
5. Current Setup
4. Thermal Expansion ✓
3. Solar Perihelion ✓
2. Lunar Perigee ✓
1. Spring Alignment ✓

+10–14 cm Steric Lift

SEVERITY FACTOR 05 • REGIONAL OCEAN CIRCULATION (OCT–DEC)

# 5/7 • Caribbean & Yucatan Currents Pile Water



Caribbean → Yucatan Current

Cayman Islands

Warm Eddies (+3–5 cm)

## Caribbean & Yucatan Currents

Trade-wind shifts dynamically stack +3 to 5 cm of water into the basin.

## Westward Caribbean Eddies

Warm clockwise eddies lift autumn sea level ~15–20 cm above winter lows.

**Local Impact: Cayman's +15–20 cm seasonal baseline lift nearly equals our entire ~25–35 cm daily tide!**

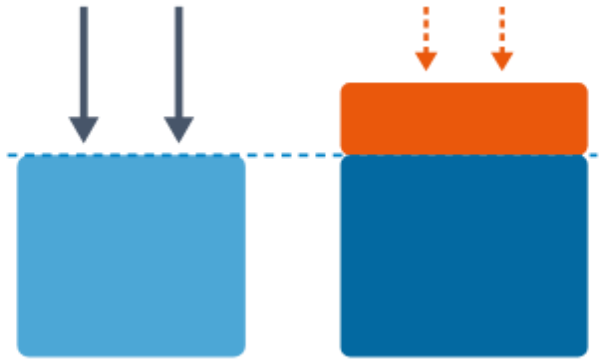
TIDE SEVERITY • 5 / 7

7. Storm Surge
6. Low Air Pressure
5. Current Setup ✓
4. Thermal Expansion ✓
3. Solar Perihelion ✓
2. Lunar Perigee ✓
1. Spring Alignment ✓

+15–20 cm Ocean Base

SEVERITY FACTOR 06 • INVERTED BAROMETER EFFECT

# 6/7 • Low Barometric Pressure Raises Sea Level



Jan/Feb: ~1016.3 mbar

~1 cm Rise / 1 mbar Drop

Oct Low: ~1011.7 mbar

## Hydrostatic Ocean Rebound

Lighter air overhead lets surrounding pressure push seawater upward.

## Cayman's 4.6 mbar Autumn Dip

Adds +4.5–5 cm baseline lift, plus +10–15+ cm during tropical waves.

**Calm-Weather Lift: Even before wind waves form, warm currents + low air pressure raise the sea ~20–25 cm!**

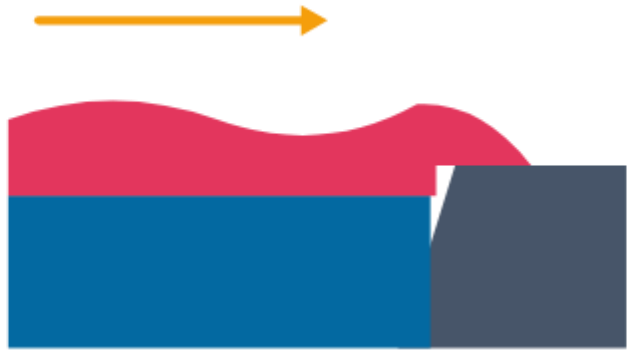
TIDE SEVERITY • 6 / 7

7. Storm Surge
6. Low Air Pressure ✓
5. Current Setup ✓
4. Thermal Expansion ✓
3. Solar Perihelion ✓
2. Lunar Perigee ✓
1. Spring Alignment ✓

6 / 7 Pre-Storm Lift

SEVERITY FACTOR 07 • PEAK HURRICANE SEASON OVERLAP

# 7/7 • Hurricane Storm Surge Atop a King Tide




## Wind-Driven Surge & Wave Churn

Cyclonic onshore winds pile churning seawater onto the coast.

## Peak Storm Season Alignment

Oct–Nov King Tides launch storm surge over ironshore roads and drains.

**Compound Flooding: Every stacked centimeter from Notches 1–6 drives meters of inland wave run-up!**

TIDE SEVERITY • 7 / 7

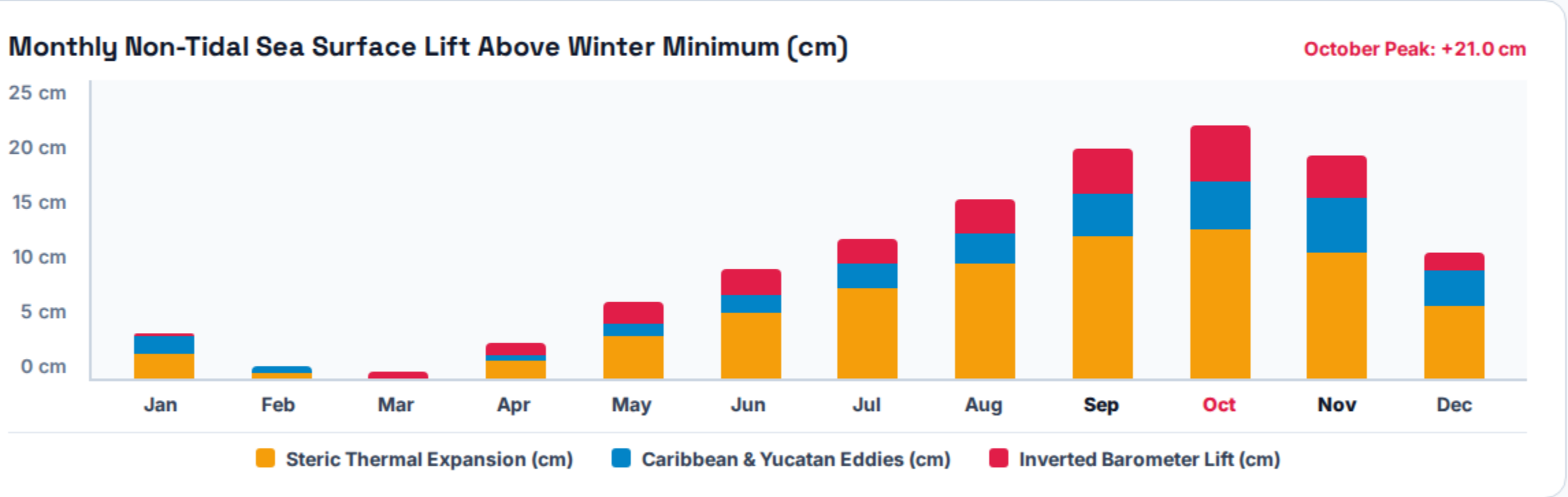
- 7. Storm Surge
- 6. Low Air Pressure ✓
- 5. Current Setup ✓
- 4. Thermal Expansion ✓
- 3. Solar Perihelion ✓
- 2. Lunar Perigee ✓
- 1. Spring Alignment ✓

MAX FLOOD RISK

ANNUAL SEA-LEVEL CYCLE • HURRICANE SEASON OVERLAP

# Grand Cayman Seasonal Sea-Level Lift

Highest water occurs Sep–Nov—right in the Cayman Islands' Hurricane Season—adding +18 to 24 cm before tides or storm surge arrive.




**October Peak (+21.0 cm) + Hurricane Season: Warm seas (+12.4 cm), eddies (+4.0 cm), and low pressure (+4.6 cm) coincide with peak storm season—making storm surge risk far more considerable.**

# Cayman’s Deep-Water Shield vs. Bay of Fundy

## Grand Cayman: Deep Trench

~0.3 m (~1 ft)



Surrounded by deep ocean trenches, tidal waves slip smoothly past with ~1 ft swing.

## Bay of Fundy: Funnel Resonance

16.3 m (53.6 ft)




12.5h funnel resonance creates 16.3 m tides—leaving Mt. Trashmore as dry high ground.