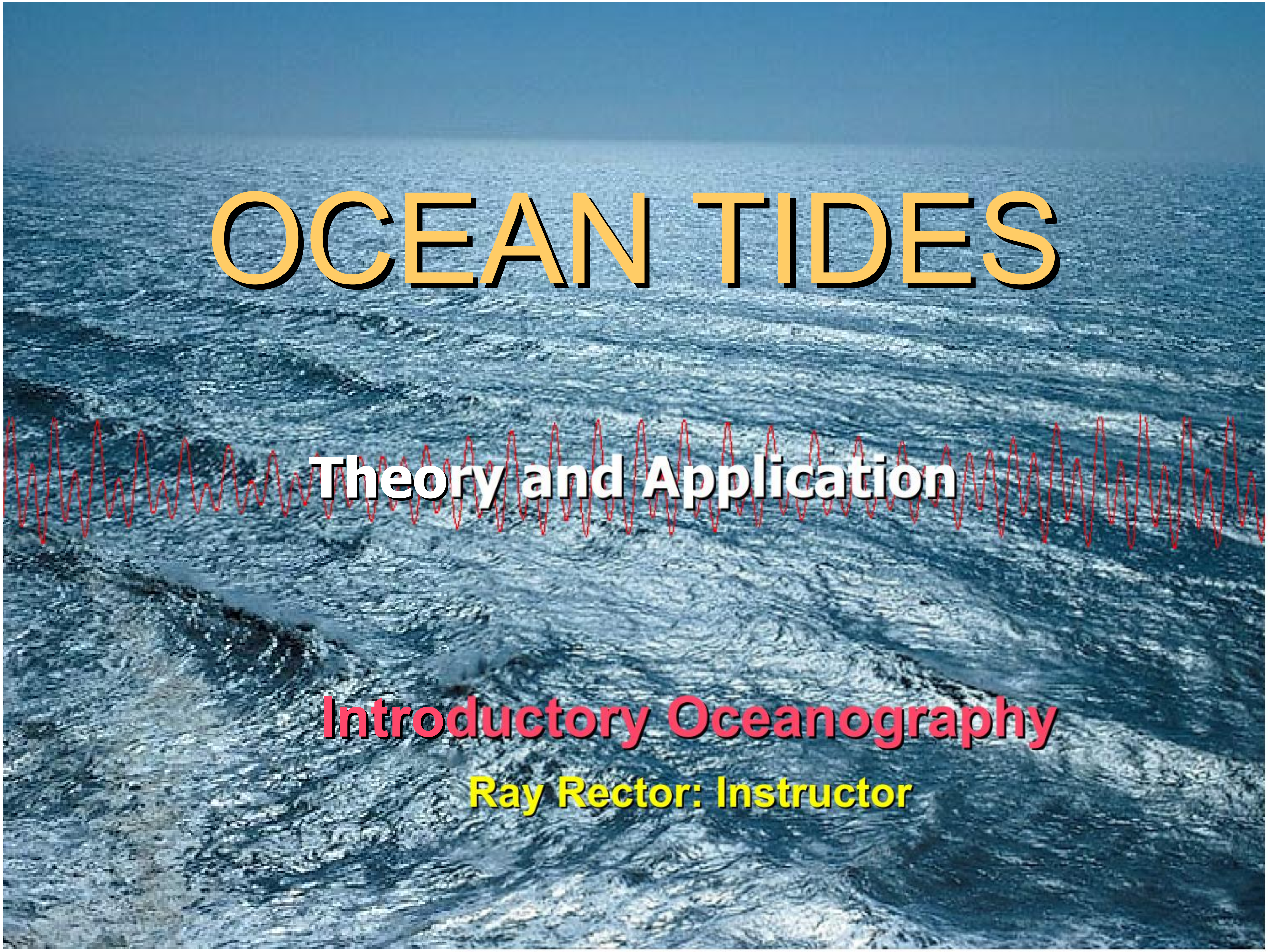
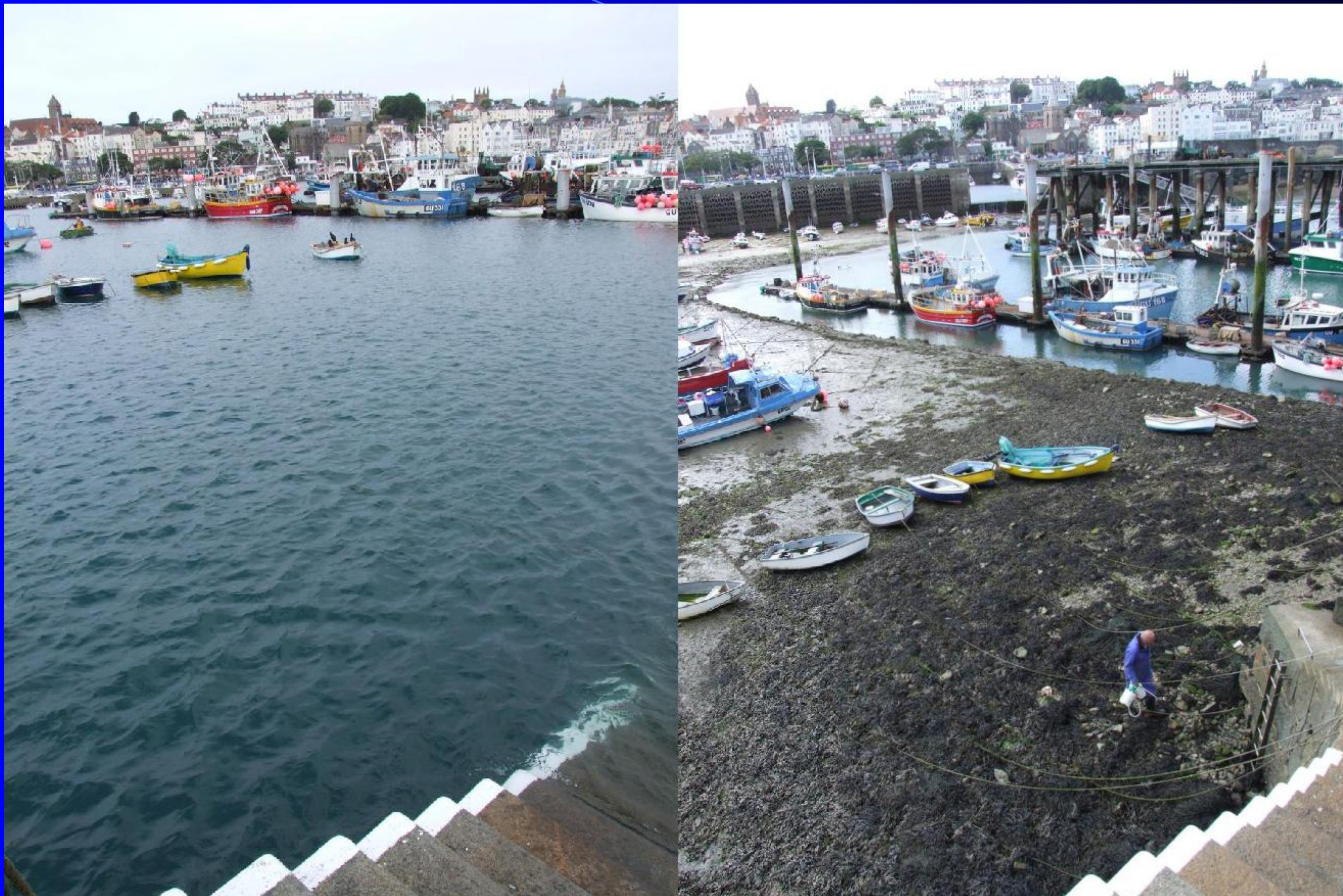

OCEAN TIDES
Theory and Application
Introductory Oceanography
Ray Rector: Instructor

Tidal Concepts

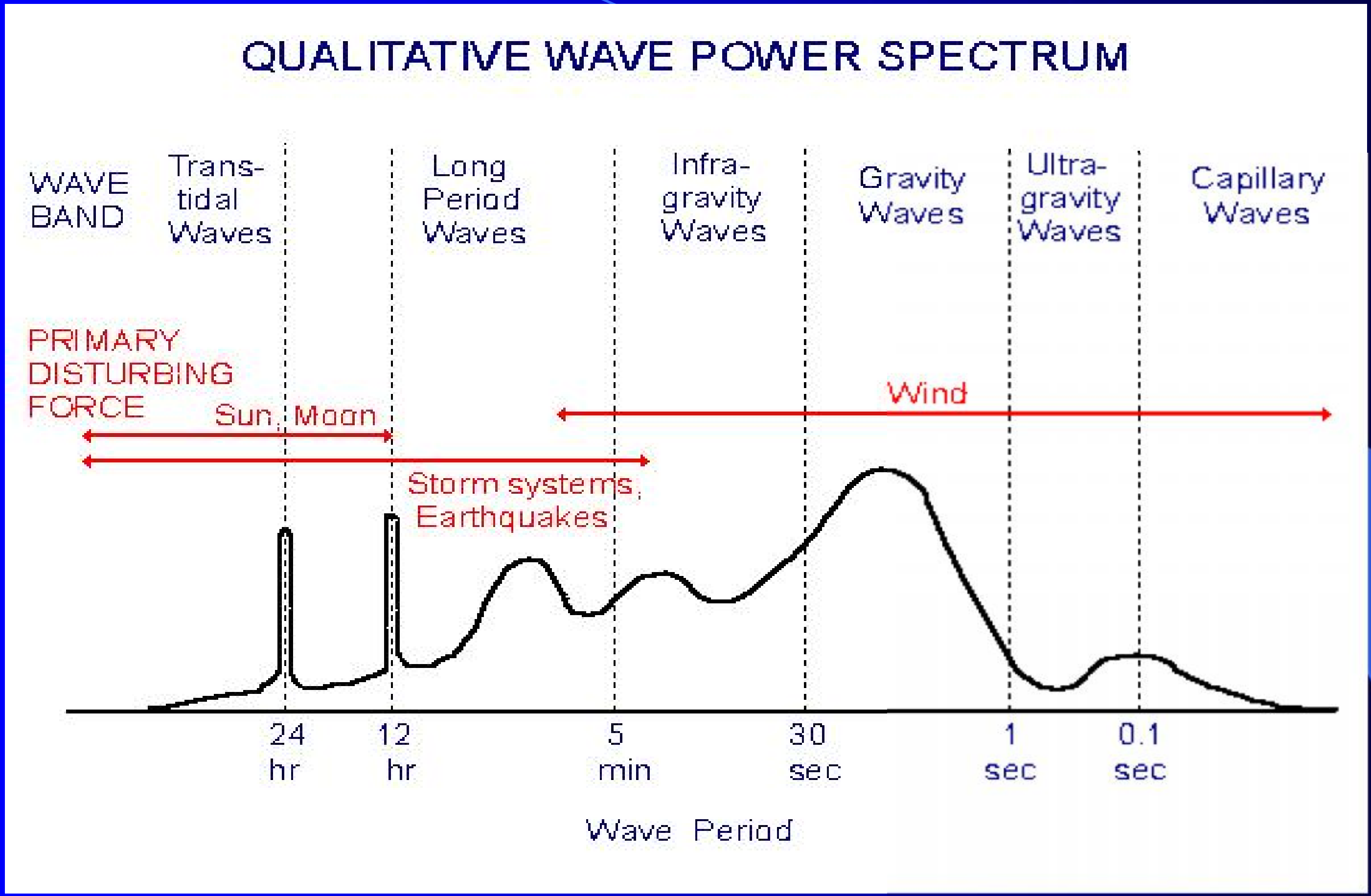
- Tides are extremely swift, very long-wavelength, shallow-water waves
- Tides are periodic short-term changes in sea level at a particular place caused by the gravitational force of the moon and sun, and the motion of the Earth
- The moon's influence is twice as great as that of the sun's
- Gravity's attractive force and inertia's flinging-away force combine to produce two ocean tidal bulges
- The Earth rotating underneath the tidal bulges causes tides
- The equilibrium theory of tides only takes into account gravitational and rotational affects under equilibrium conditions without regard to ocean basin shape, water depth, ocean inertia, Coriolis effect, nor sea bottom friction drag
- The dynamic theory of tides is a much more robust prediction model that also - takes account all those factors left out of the equilibrium theory (listed above)
- Tidal patterns take three forms worldwide: diurnal, semidiurnal, and mixed
- Tides in each ocean basin form a rocking-rotary cycle around *amphidromic* "no tide" points – counterclockwise in N. Hemi, clockwise in the S. Hemi

Bay of Fundy



[Time-lapse Video of Bay of Fundy Tides]

Ocean Wave Energy



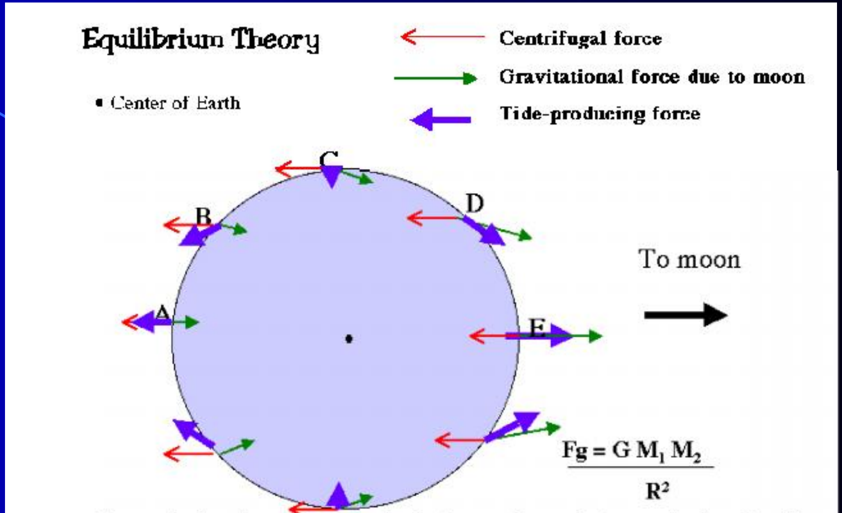
Schematic guestimation of the energy (power spectrum) contained in the surface waves of the ocean

Reference: Kinsman, Blair, Wind Waves: Their Generation and Propagation on the Ocean Surface. Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1965, p. 23.

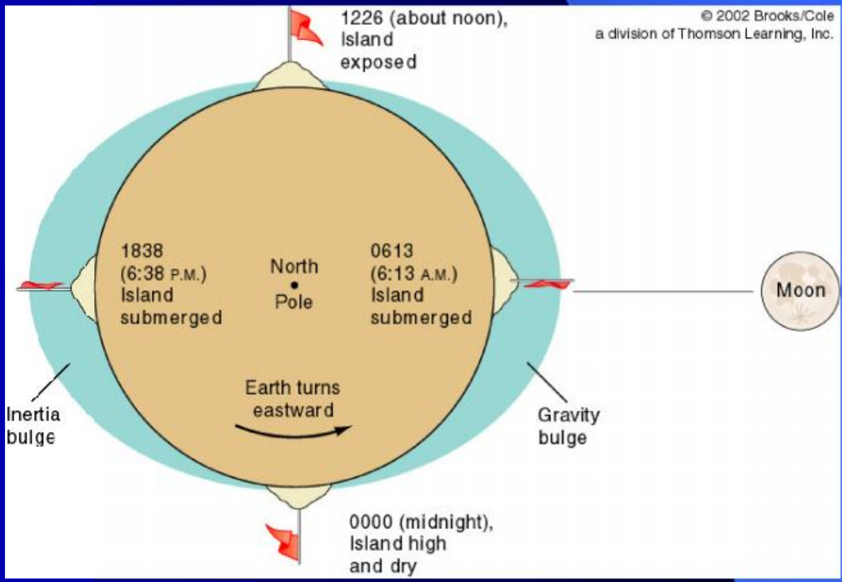
Equilibrium Theory of Tides

Concepts

- ❖ Equilibrium theory of tides combines the fundamentals of Newtonian celestial gravity and inertia mechanics and a rotating Earth to predict the tides
- ❖ Equilibrium theory assumes that
  - ✓ Ocean surface is at equilibrium with forces acting upon it
  - ✓ Idealized bottomless ocean column
  - ✓ No landmass obstructions
  - ✓ No Coriolis effect
- ❖ Equilibrium theory of tides predicts
  - ✓ Two tidal bulges
  - ✓ Two highs and low tides per day
  - ✓ Tidal amplitudes of less than 1 meter
- ❖ Equilibrium theory fails to predict:
  - ✓ Two-meter plus tides
  - ✓ Diurnal and mixed tide patterns
  - ✓ Slow tidal wave velocities
  - ✓ Amphidromic rotary tide movements



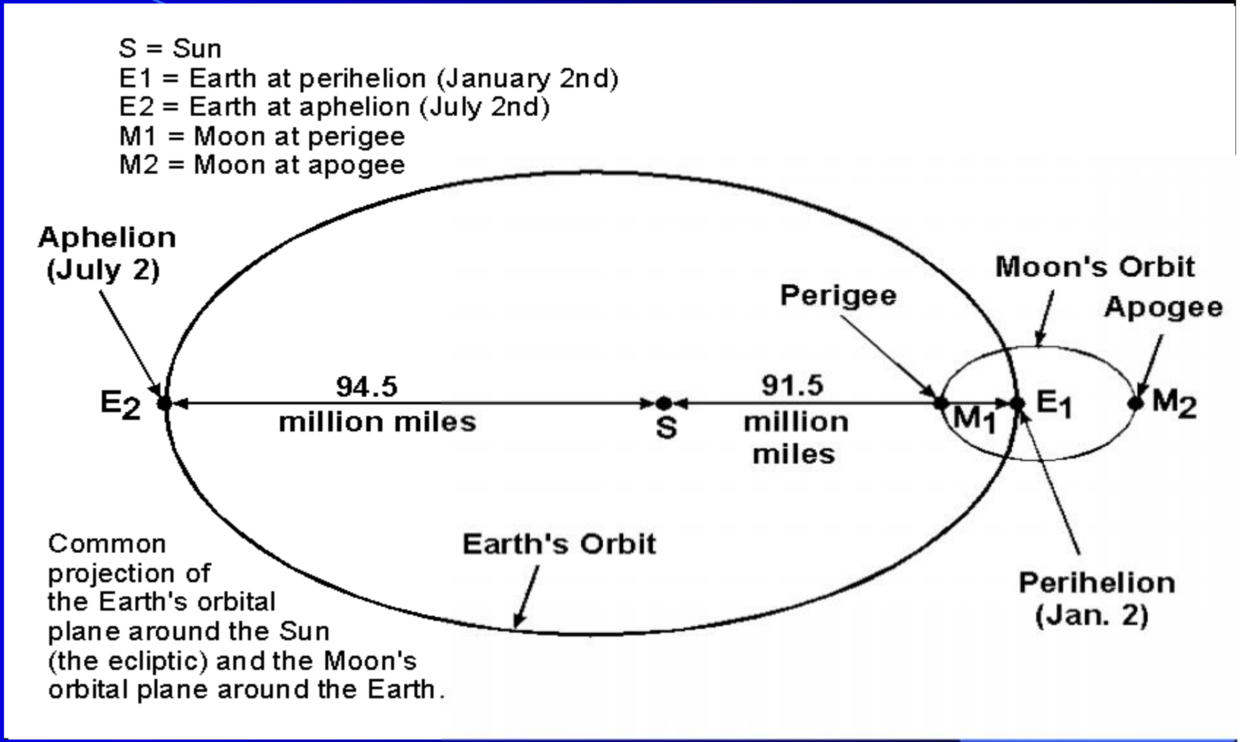
The tide producing force at any point is the resultant of the gravitational and centrifugal forces at that point and varies inversely with the cube of the distance from the moon. *How is that possible with R^2?*



Earth – Moon – Sun Relationship

Earth's Orbit

- ❖ ***Perihelion***
  - ✓Closest to Sun
  - ✓January 2nd
- ❖ ***Aphelion***
  - ✓Farthest from Sun
  - ✓July 2nd



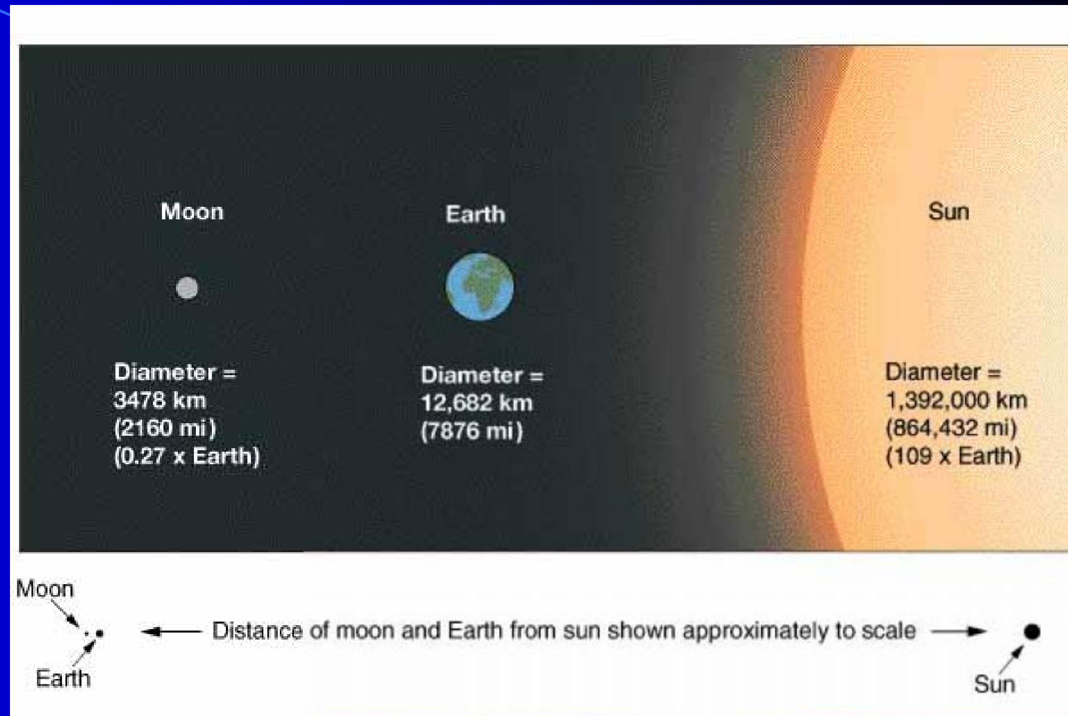
Moon's Orbit

- ❖ ***Perigee***
  - ✓Closest to Earth
  - ✓Twice a month
- ❖ ***Apogee***
  - ✓Furthest from Earth
  - ✓Twice a month

Earth – Moon – Sun Relationship

Mass vs. Distance

- Sun is 27 million times more massive than Moon
- Earth is 81 times more massive than the Moon
- The Sun is 387 times farther away from Earth than the moon
- Solar tidal effect is only 46% that of the moon



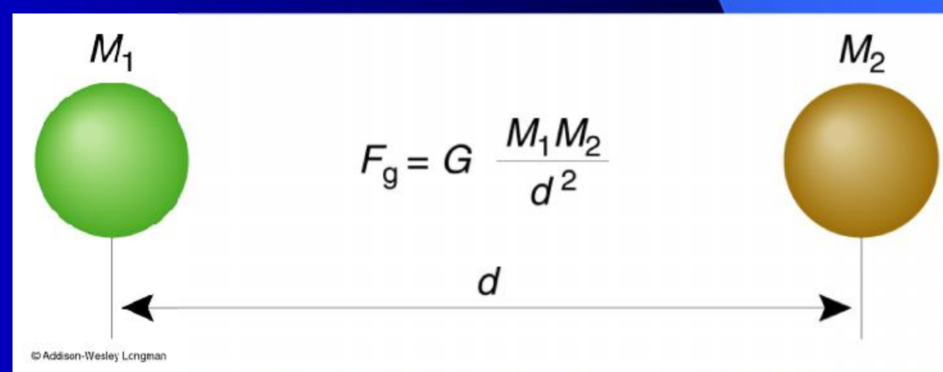
Gravitational Relationship

m1 = gravitational pull of 1st planet

m2 = gravitational pull of 2nd planet

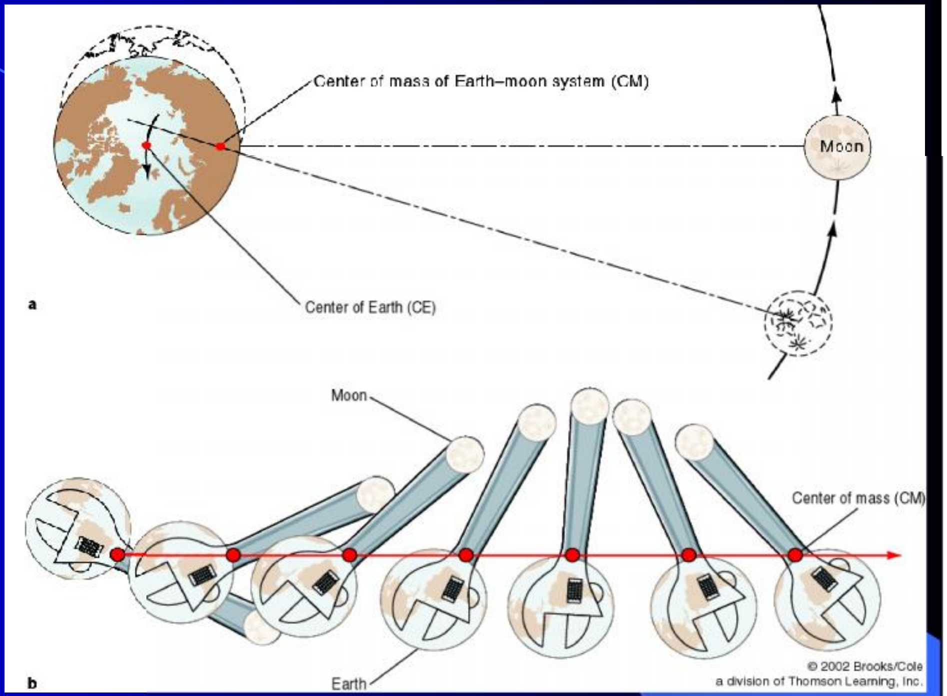
d = distance between the planets

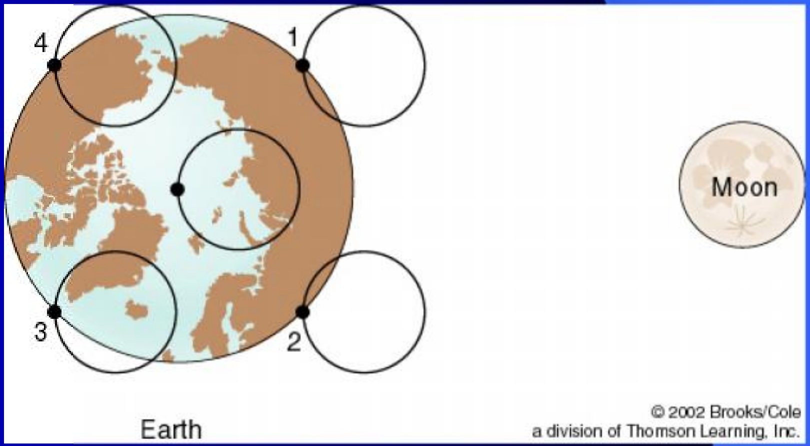
G = gravitational constant



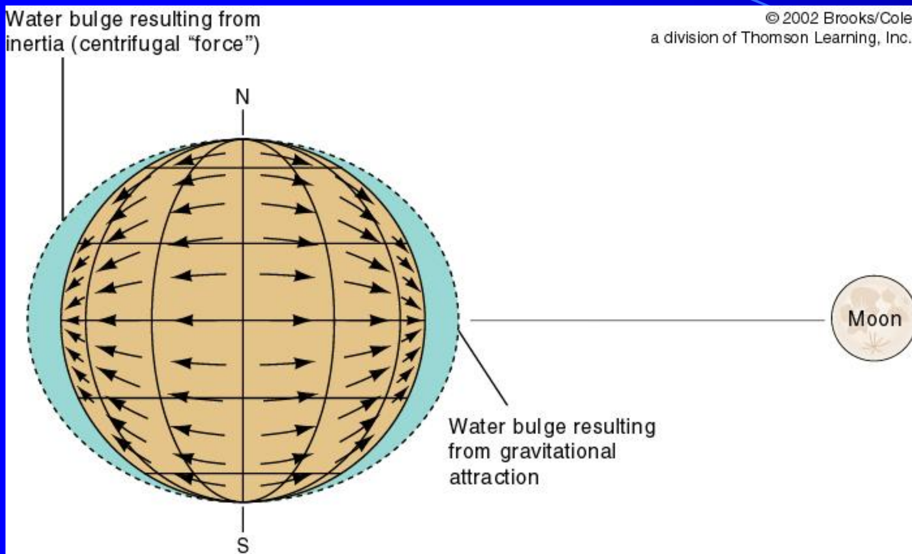
Revolving Earth- Moon System

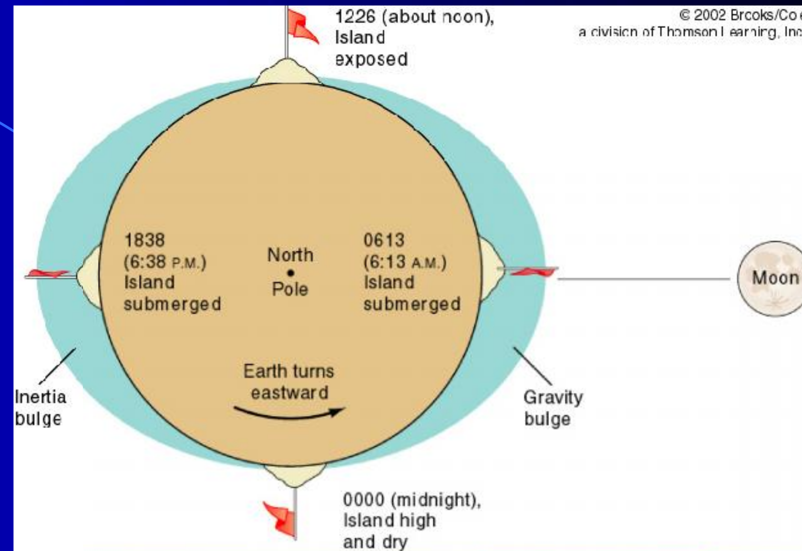
- ❖ Moon and Earth revolve around a mutual center of mass
- ❖ Revolution cycle = 29.5 days
- ❖ Common center of mass is located 1,650 kilometers beneath the Earth's surface
- ❖ A perfect balance between gravitational attraction and inertial repulsion keeps the two bodies in stable orbit around one another
- ❖ Gravity, inertia, and a rotating Earth, are the root causes of tides





Earth's Twin Tidal Bulges



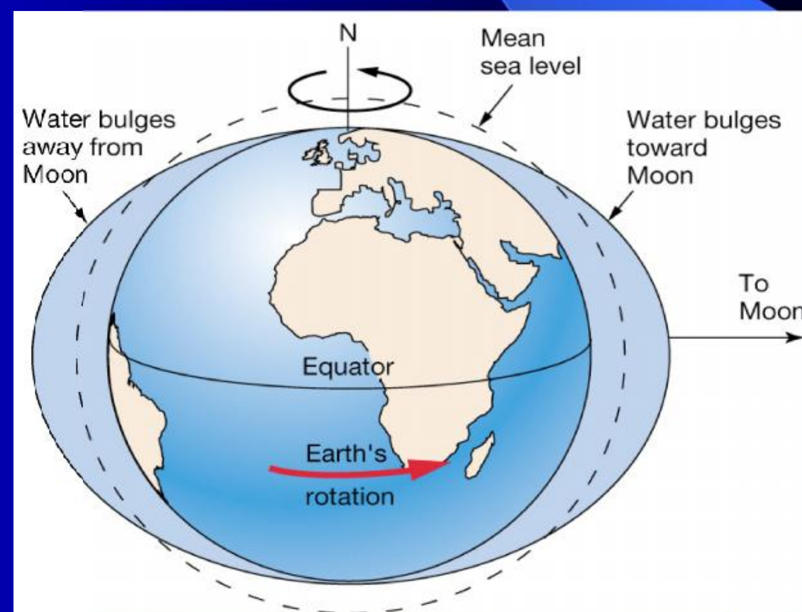


❖ Earth has two tidal bulges:

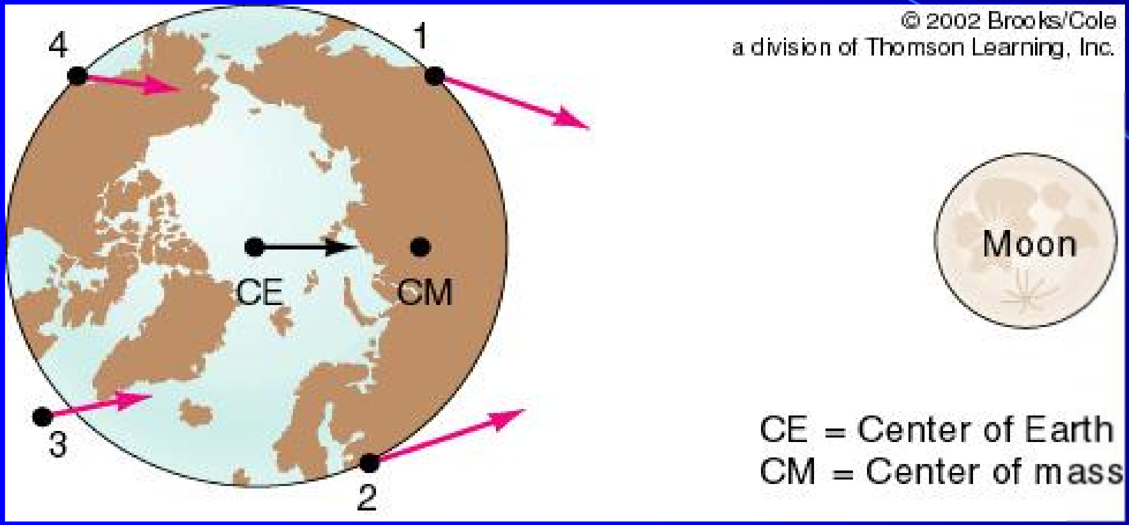
1) Inertia bulge

2) Gravity bulge

❖ Tidal bulges move west to east due to Earth's rotation

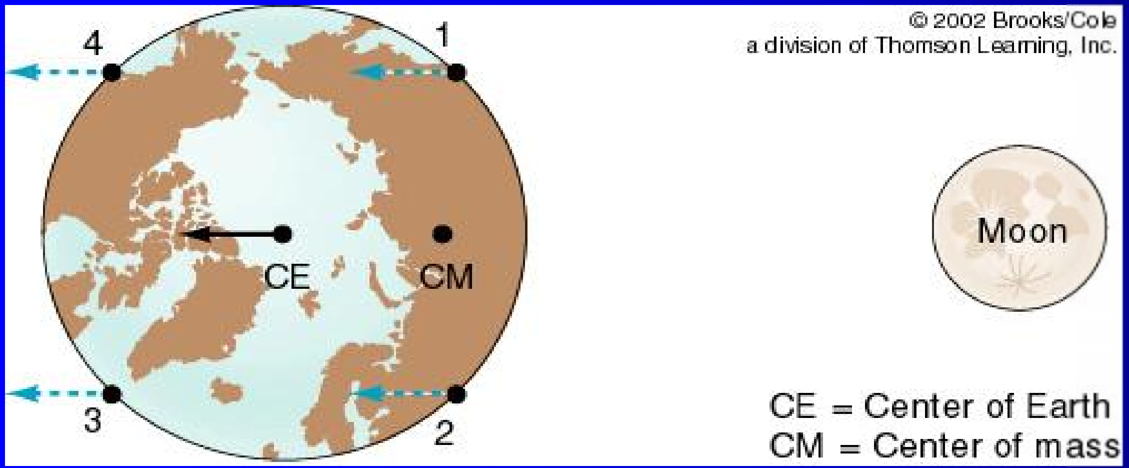


Tide-Generating Forces



Gravity (pulling-toward force)

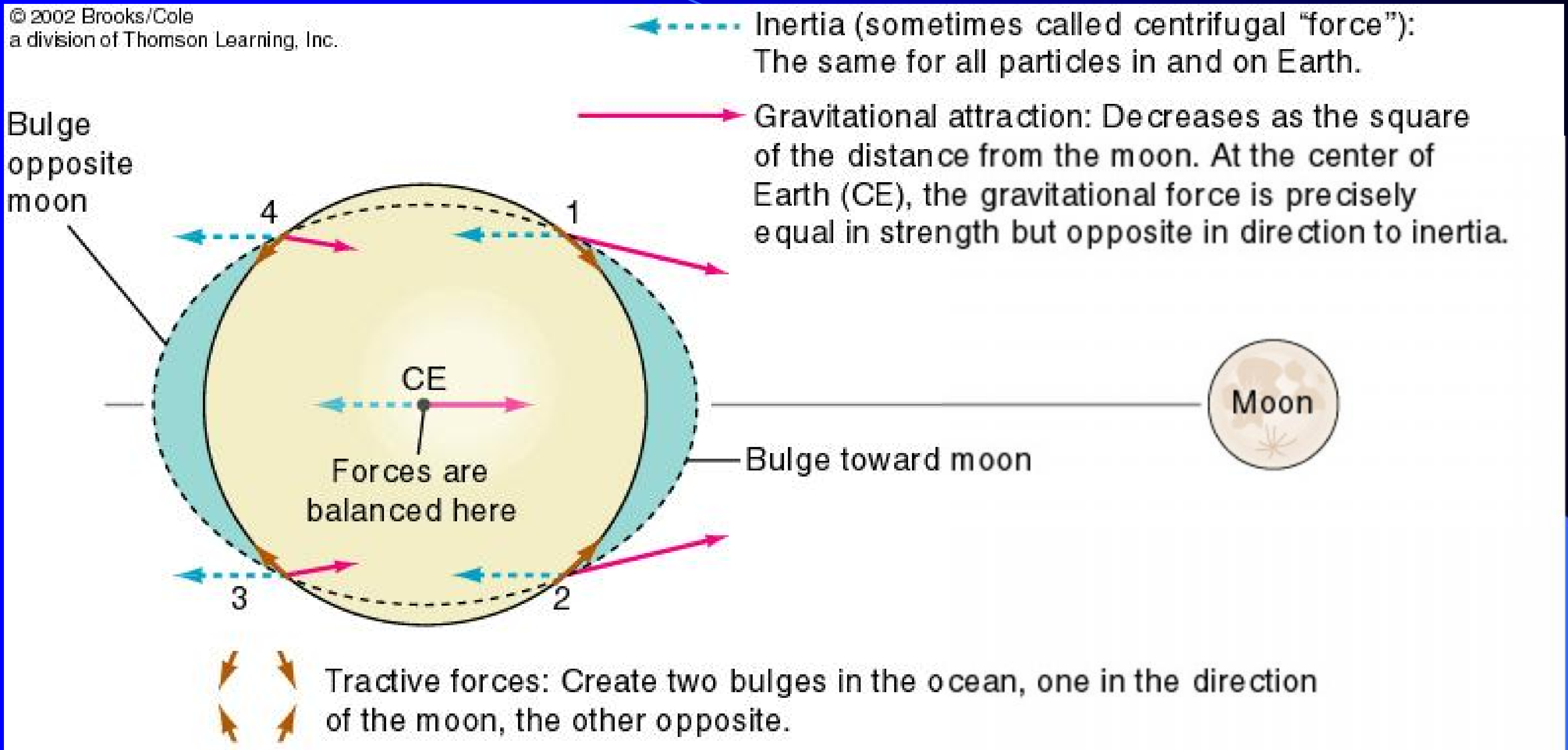
- ✓ Attractive force
- ✓ Unequally distributed
- ✓ Unequally directed
- ✓ Strongest nearest moon



Inertia (flinging-away force)

- ✓ Centrifugal effect
- ✓ Repelling force
- ✓ Equally distributed
- ✓ Equally directed

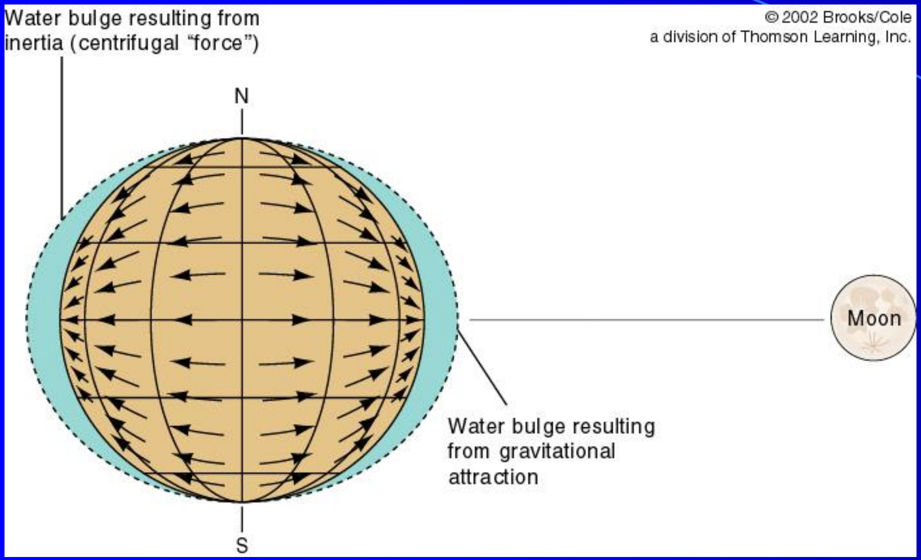
Interaction of the Tidal Forces

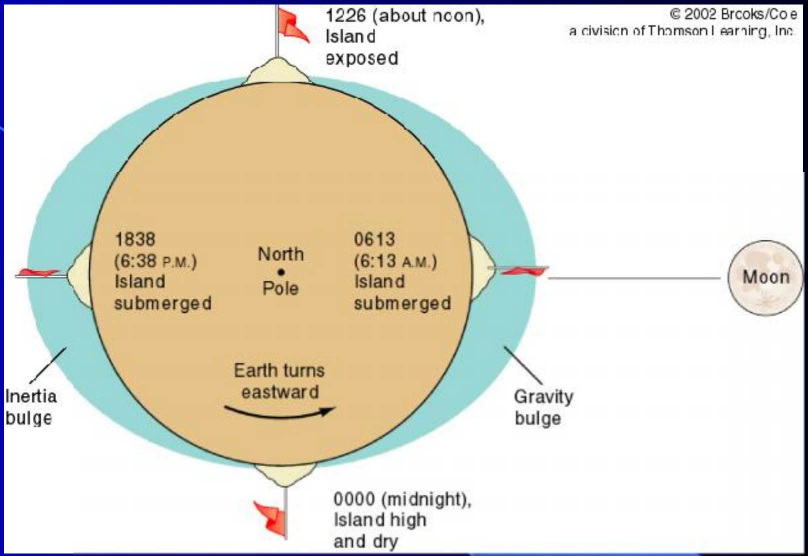


The two forces that can move the ocean are balanced only at the center of Earth (point CE). Elsewhere the net imbalance is a small force that causes ocean water to converge into two equal "bulges," as shown.

✓**The combined forces of gravitational attraction and inertia create a net balanced force called "tractive forces"**

Earth's Twin Tidal Bulges



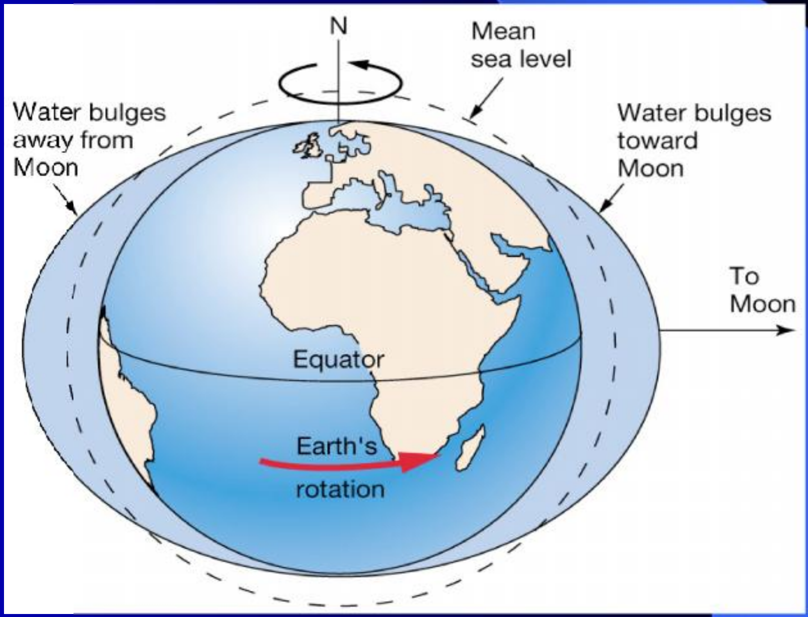


❖ Earth has two tidal bulges:

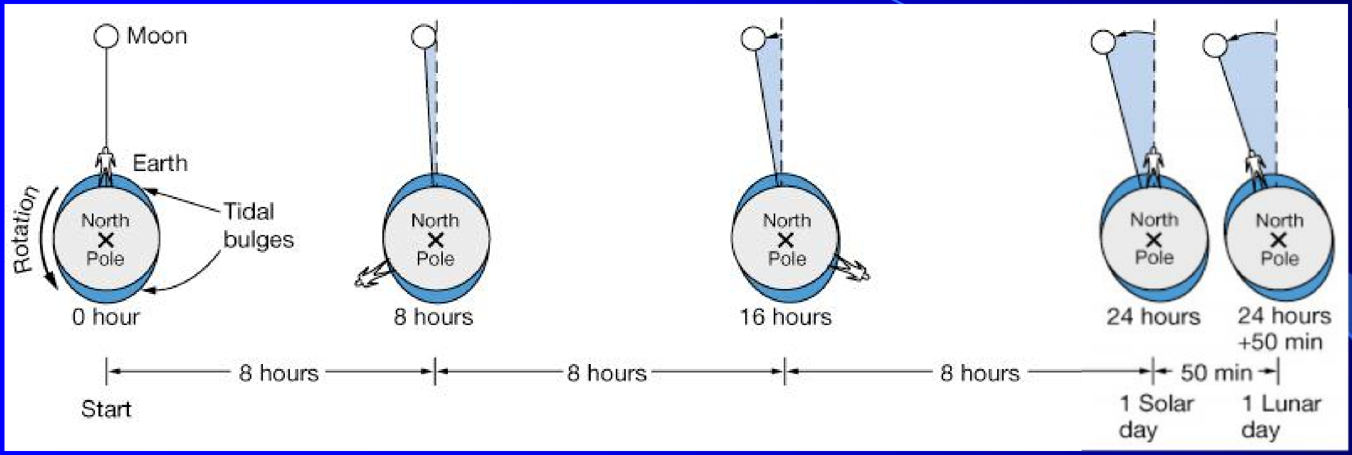
1) Inertia bulge

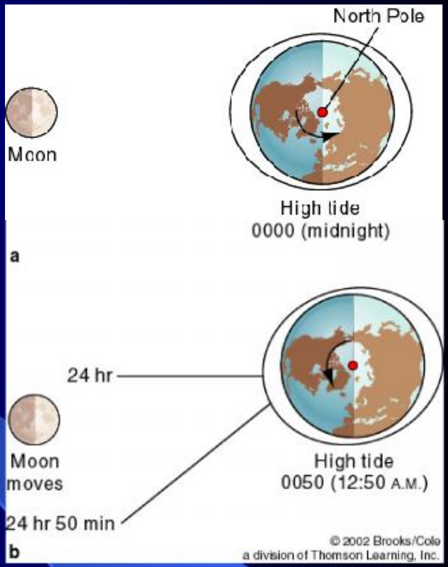
2) Gravity bulge

❖ Tidal bulges move west to east due to Earth's rotation



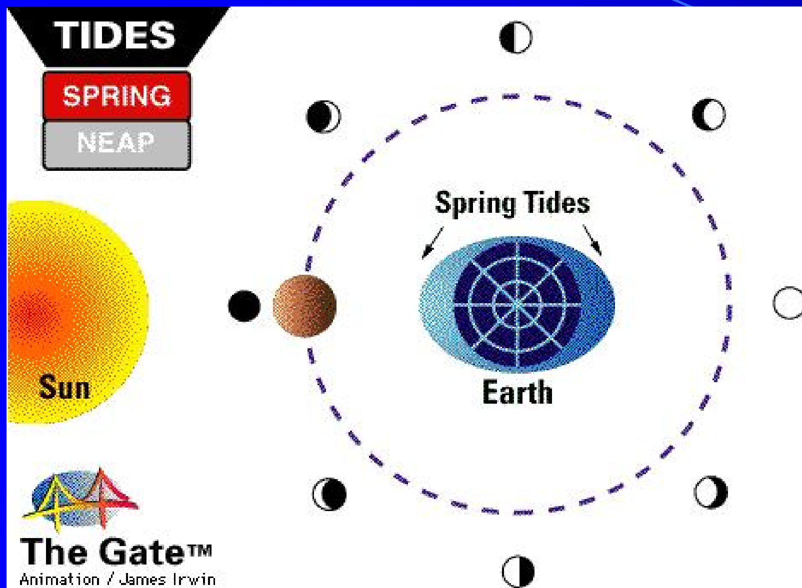
The Lunar - Tidal Day

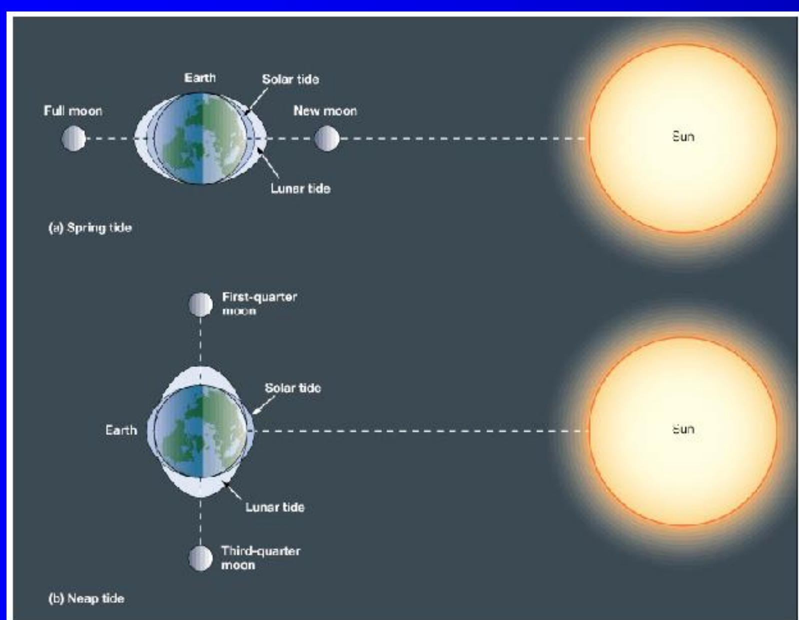




- **Solar Earth Day** - Earth completes one rotation relative to the sun in 24 hours
- **Lunar Earth Day** - Earth completes one rotation relative to the moon in 24 hours 50 minutes
- Earth – Moon System completes one revolution in 29.5 days (one lunar month/cycle) or 1/12 of a revolution in one solar Earth day
- One Lunar Tidal Cycle = 24 hours 50 minutes
- Arrival of a new tide cycle occurs 50 minutes later each day

Spring Tide Versus Neap Tide





Spring Tide

- Gravitational pull of the sun and moon are in line with each other
- Daily tidal variations on Earth are at their greatest
- Occur during new and full moon phases

Neap Tide

- Gravitational pull of the sun and moon are at right angles to each other
- Daily tidal variations on Earth are at their least
- Occur during first and last quarter of the moon

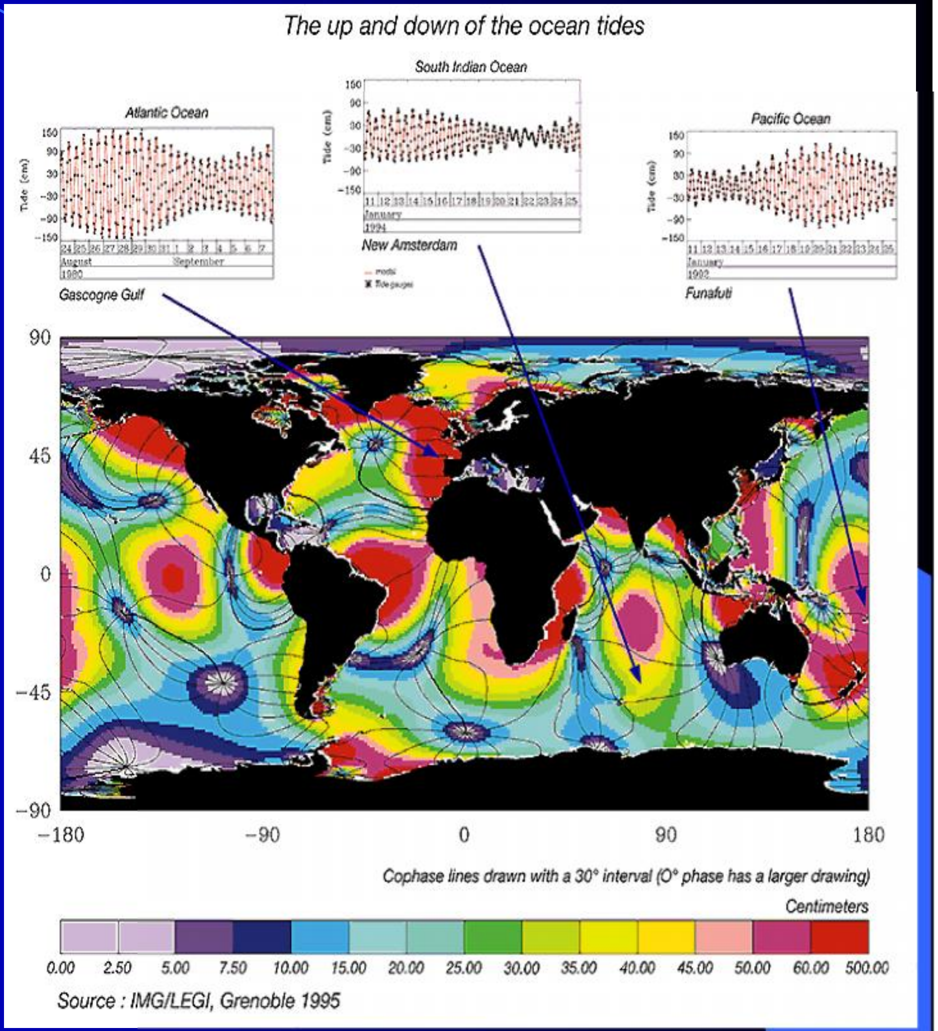
The Dynamic Theory of Tides

Concepts

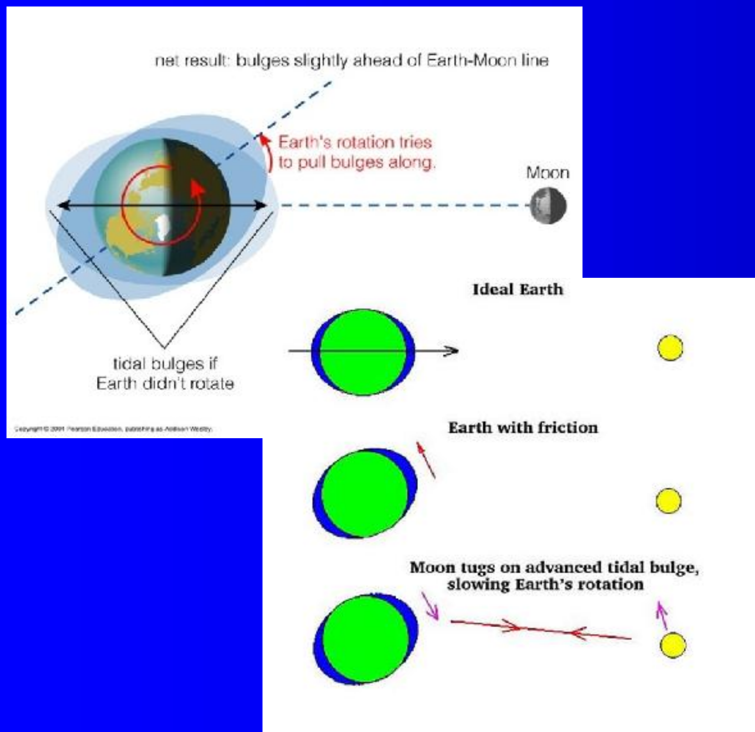
- Dynamic theory of tides combines the fundamentals of the equilibrium theory with several major fluid motion problems related to:
  - ✓ Landmass obstructions
  - ✓ Ocean basin shape
  - ✓ Friction drag of sea bottom
  - ✓ Shallow-water wave behavior
  - ✓ Coriolis effect
  - ✓ Inertia of water column

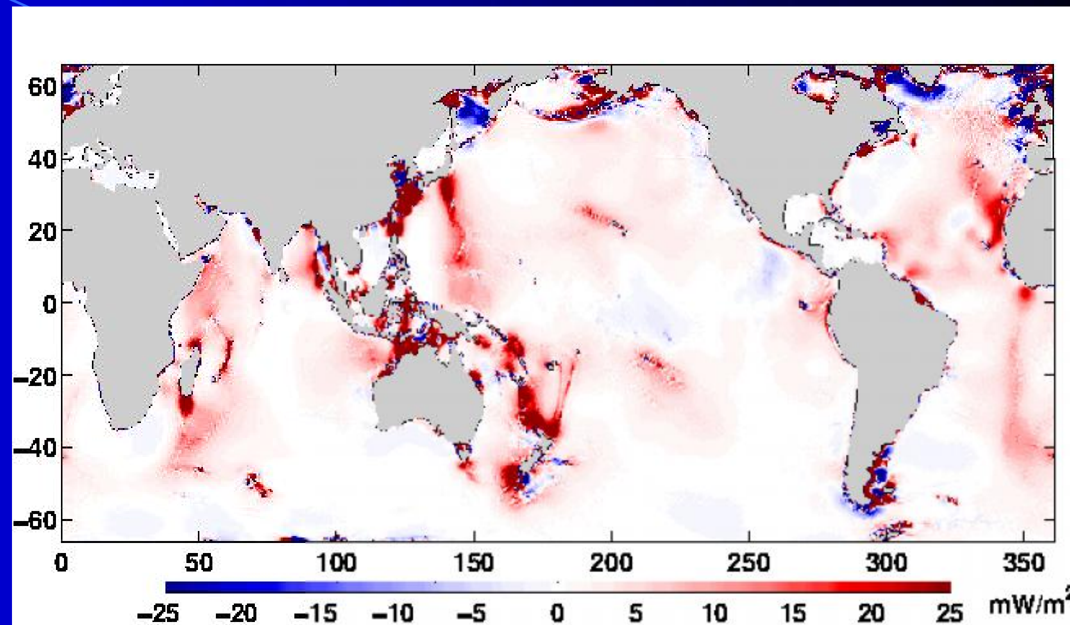
- Dynamic theory of tides explains the differences between predictions based on Newton's equilibrium model and the actual observed behaviors of tides

- Actual tidal movement is modeled as a basin-scale set of interconnected amphidromic rotary wave circuits



Tidal Bulges and Sea Bottom Drag

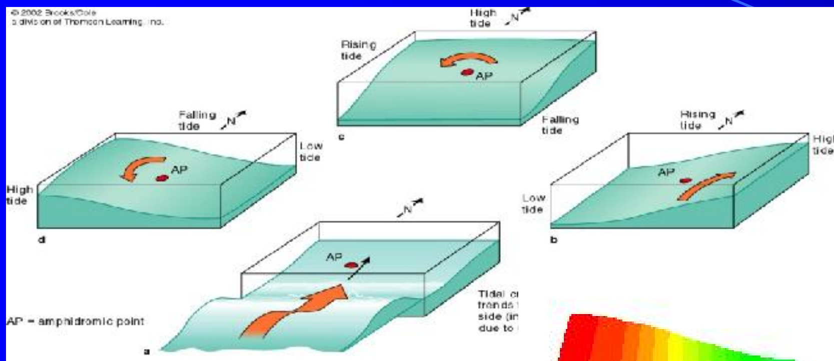


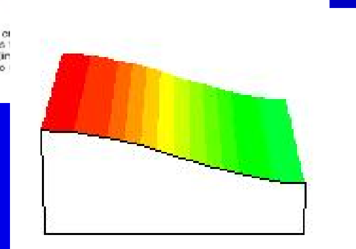


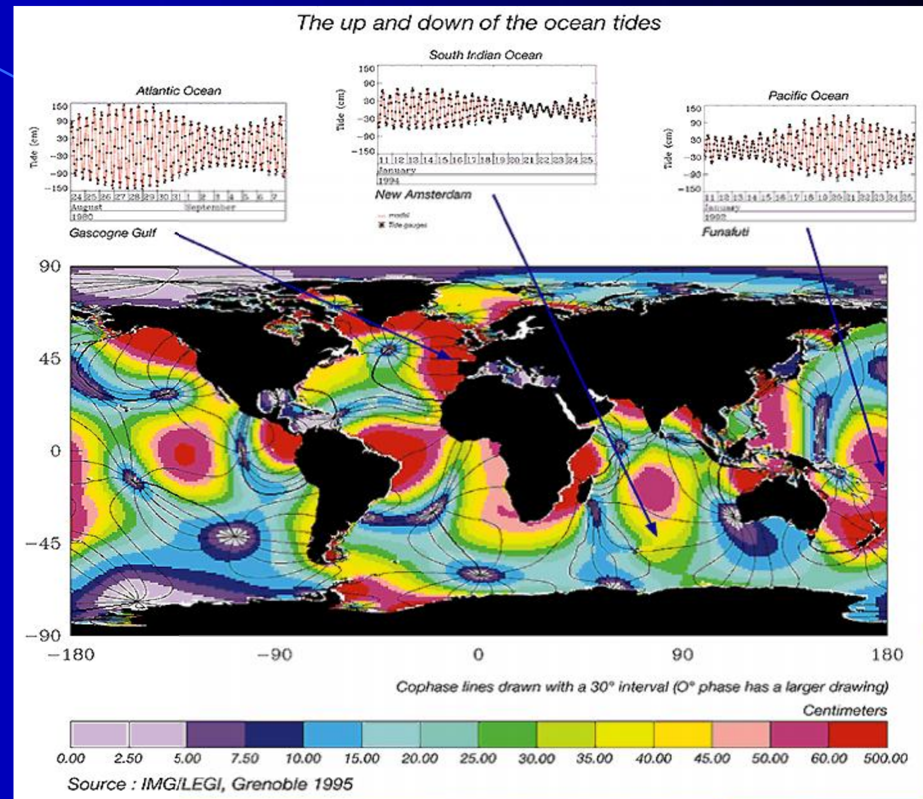
Regions of Greatest Tidal Drag

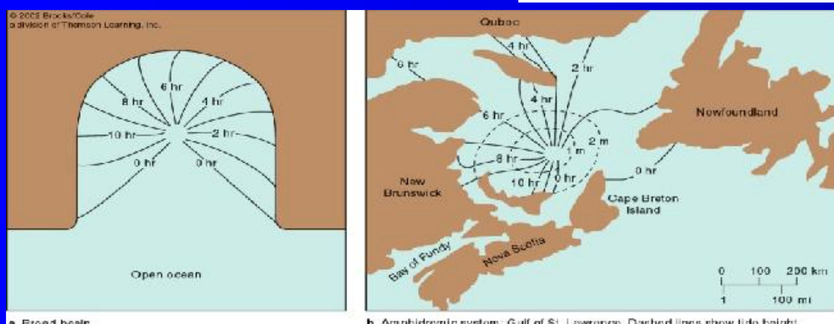
- ❖ Earth rotates beneath tidal bulge
- ❖ Frictional drag between ocean column and sea bottom pulls tidal bulge eastward of Earth-moon centerline
- ❖ Ocean water column inertia also causes tidal bulge to lag behind the predicted “equilibrium model” bulge

Amphidromic Rotary Standing Waves



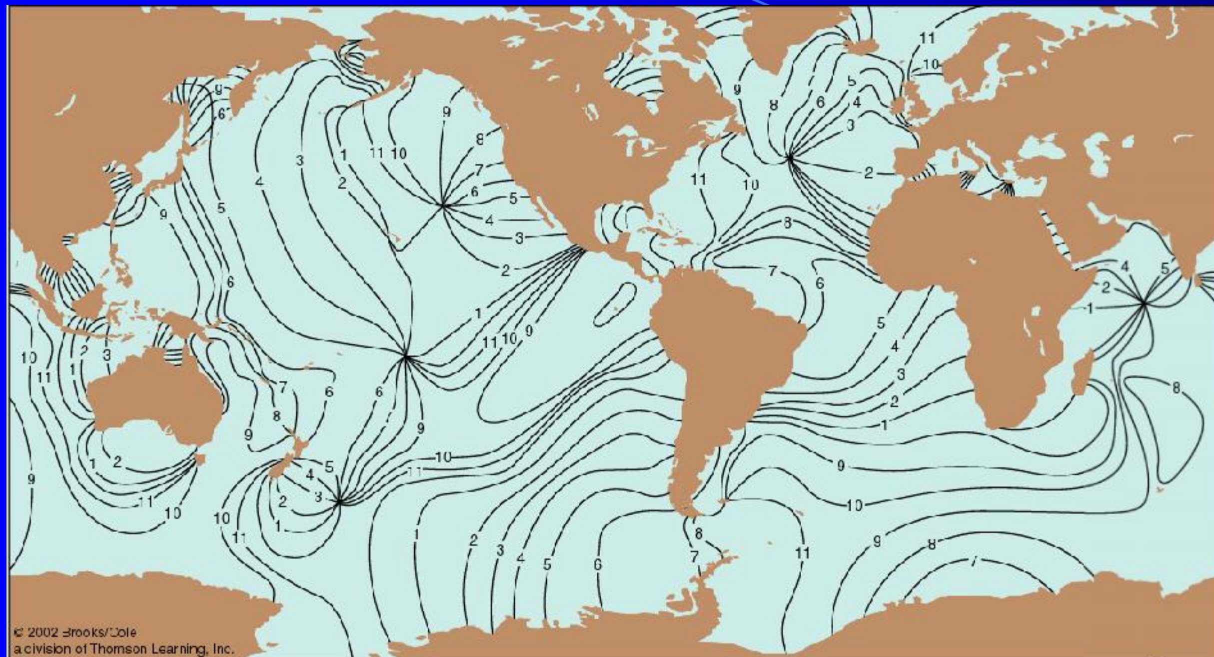


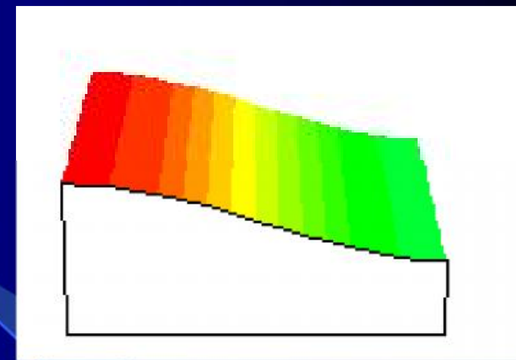


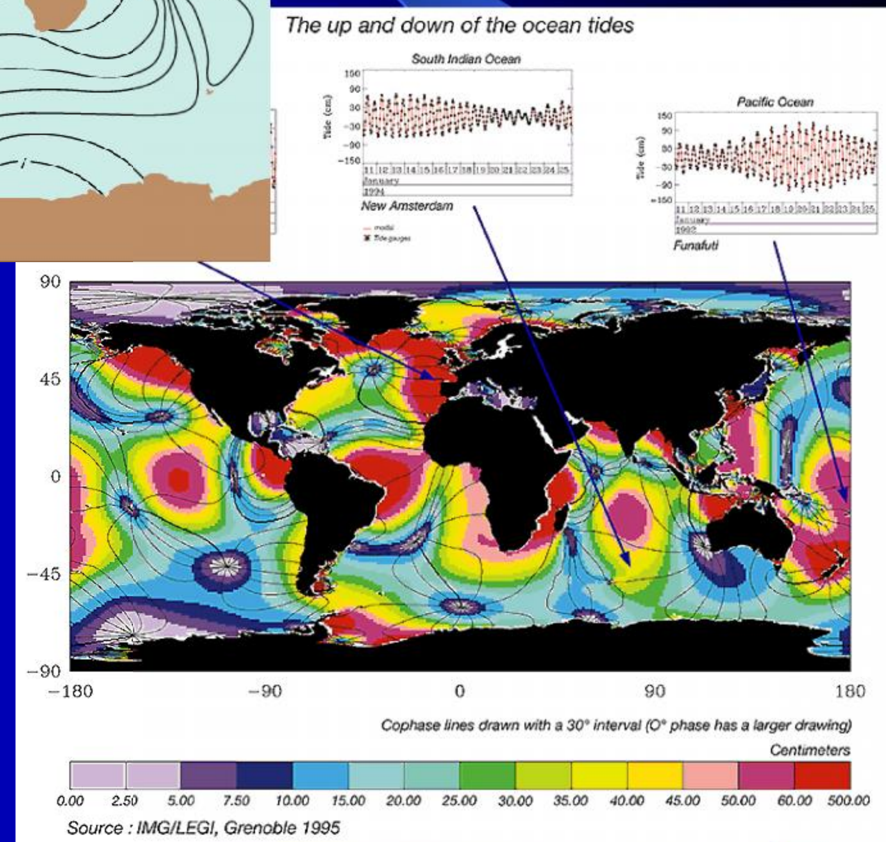


- ❖ Coriolis effect plays major part in causing rotary tide motion
- ❖ Centerpoint of the tide's rotational standing wave is termed the "amphidromic node" where zero tides occur
- ❖ Tide amplitude increases with distance from node points
- ❖ Counterclockwise rotation in the N. Hemi – clockwise rotation in S. Hemi

Amphidromic Tidal Systems





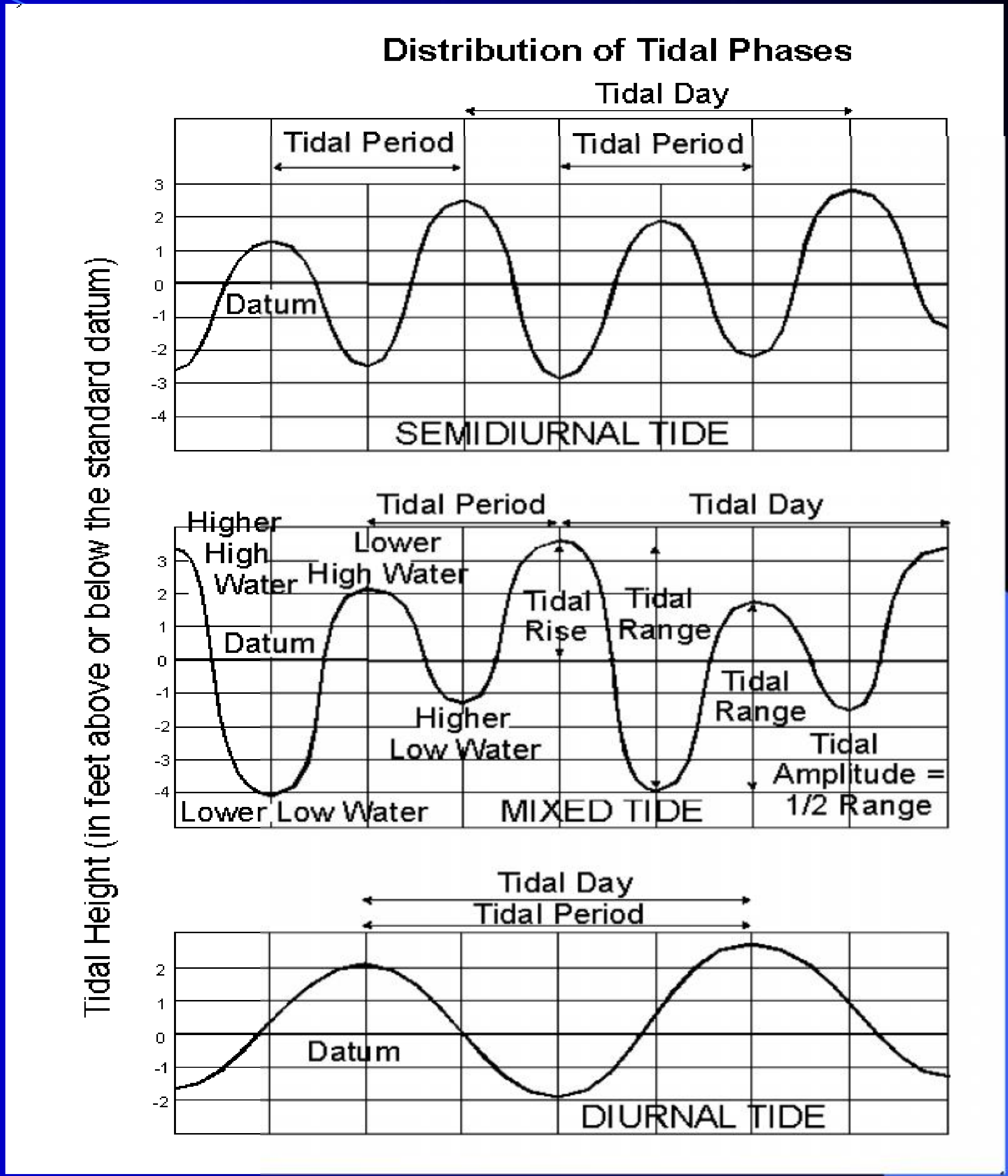


- Tide amplitude varies with distance from node points
- Zero tide at node points
- Overlapping of amphidromic systems
- Pacific basin most complicated

Ocean Tide Terminology

Important Terms

- Mean Sea Level
- Tidal datum
- Tidal day
- Tidal period
- Tidal range
- Tidal amplitude
- Tidal phases
- Neap and spring tide
- Higher high water
- High water
- Low water
- Lower low water
- Ebb, slack, and flood

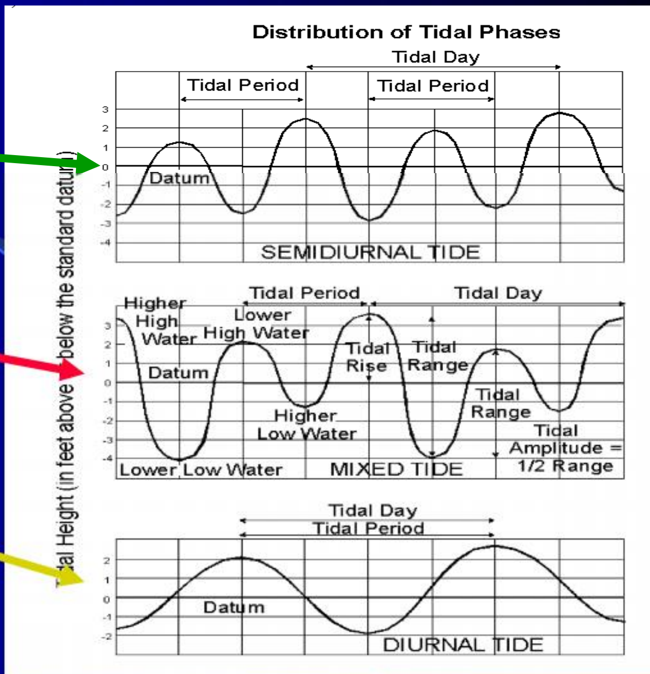


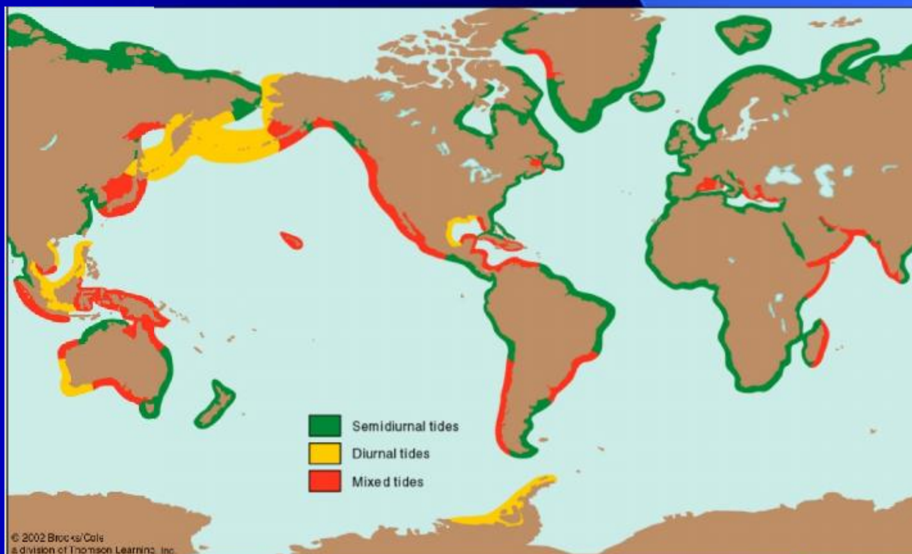
Three Patterns of Ocean Tides

1) **Semidiurnal Tide**
   - ✓ Two highs, two lows
   - ✓ Highs and lows similar
   - ✓ Atlantic and Arctic Oceans

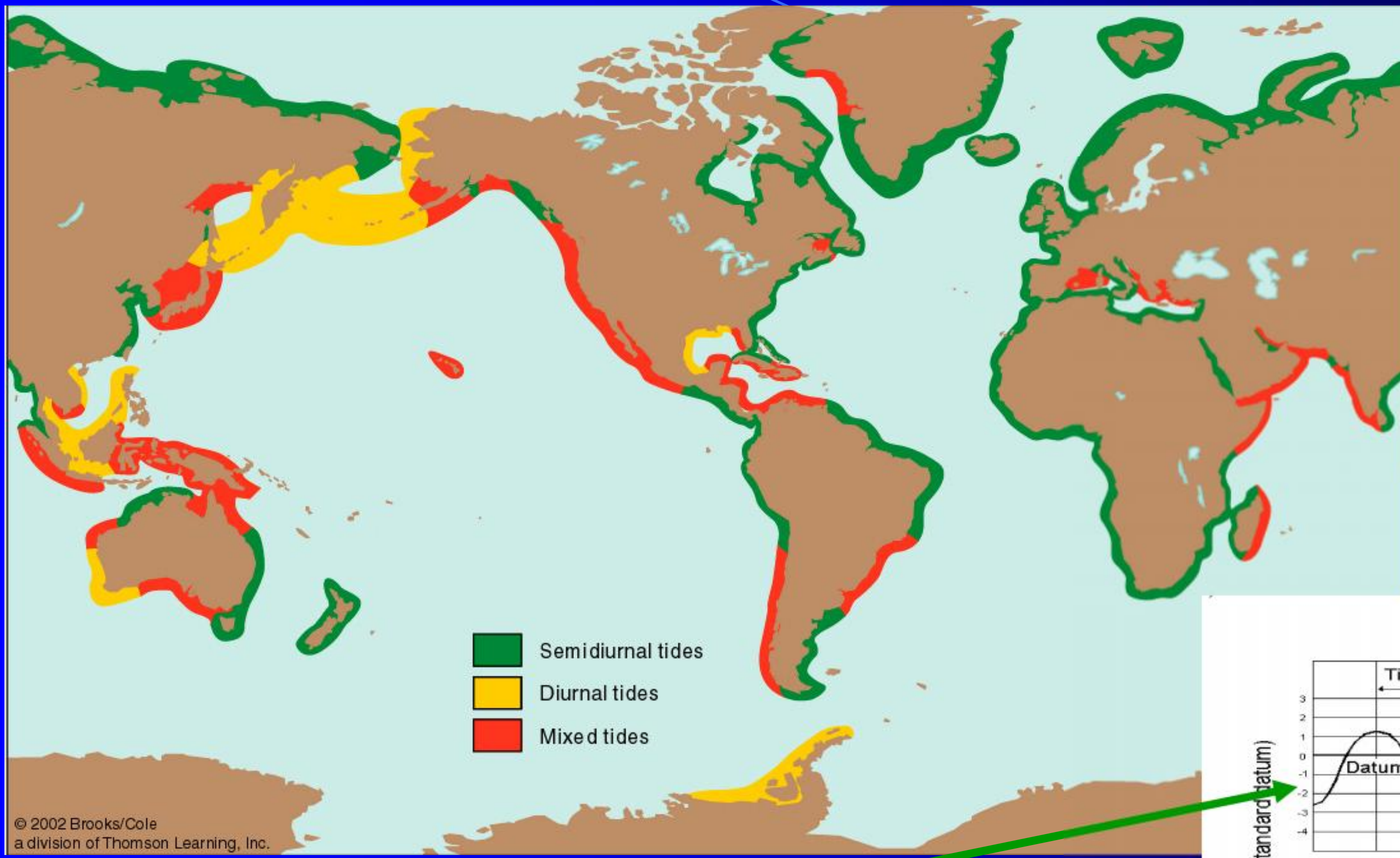
2) **Mixed Tide**
   - ✓ Two highs, two lows
   - ✓ Highs and lows dissimilar
   - ✓ Pacific and Indian Oceans

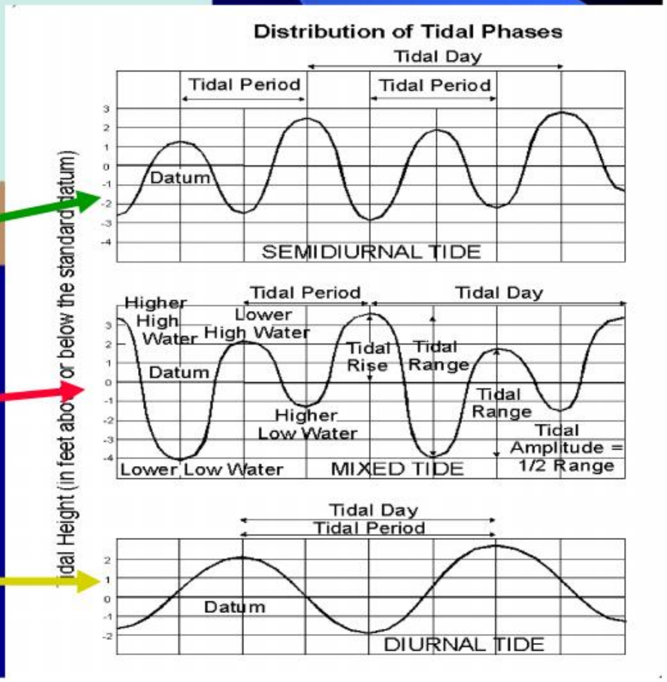
3) **Diurnal Tide**
   - ✓ One high, one low
   - ✓ Aleutians, Indonesia and Gulf of Mexico





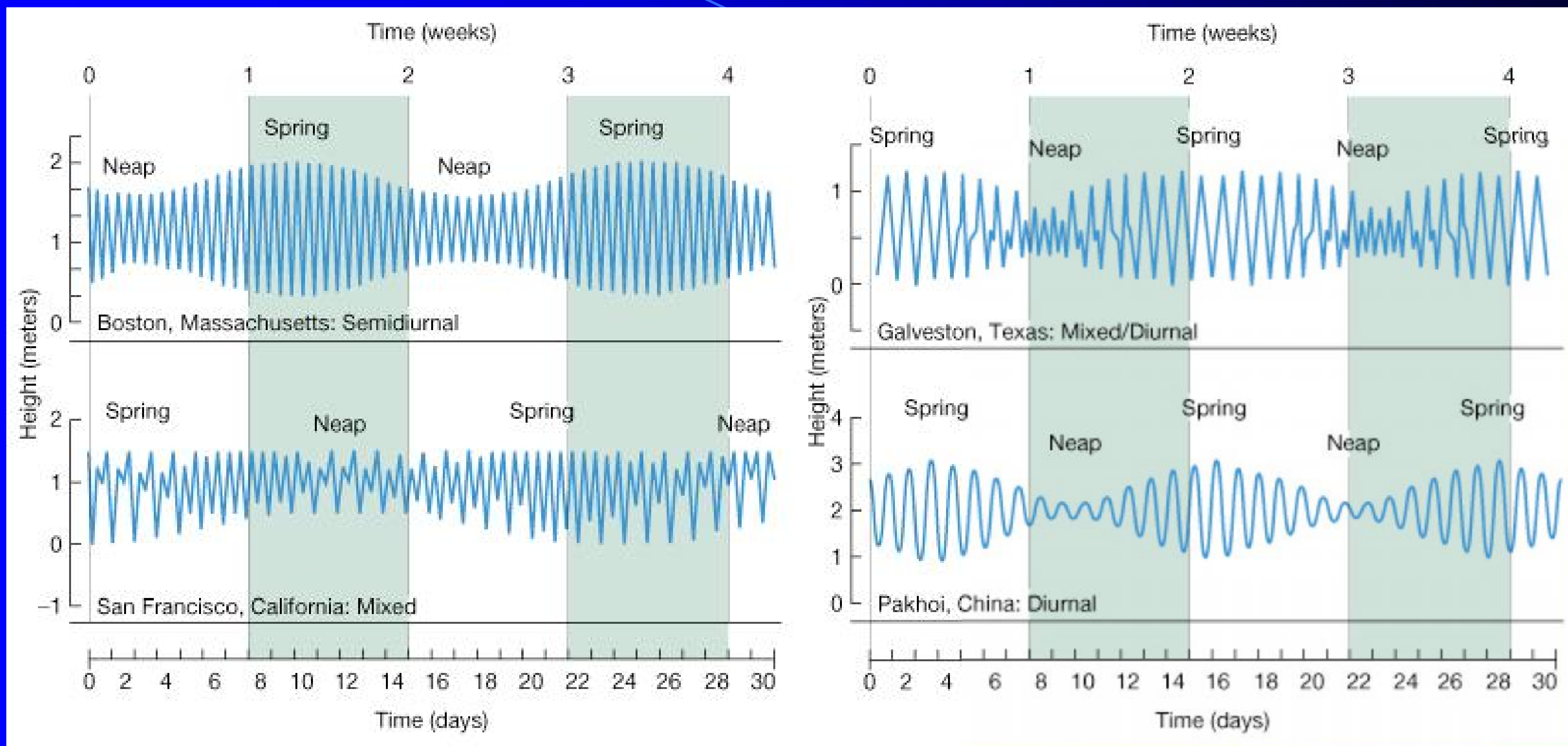
Three Patterns of Ocean Tides





1) Semidiurnal Tide
2) Mixed Tide
3) Diurnal Tide

Monthly Tidal Cycles



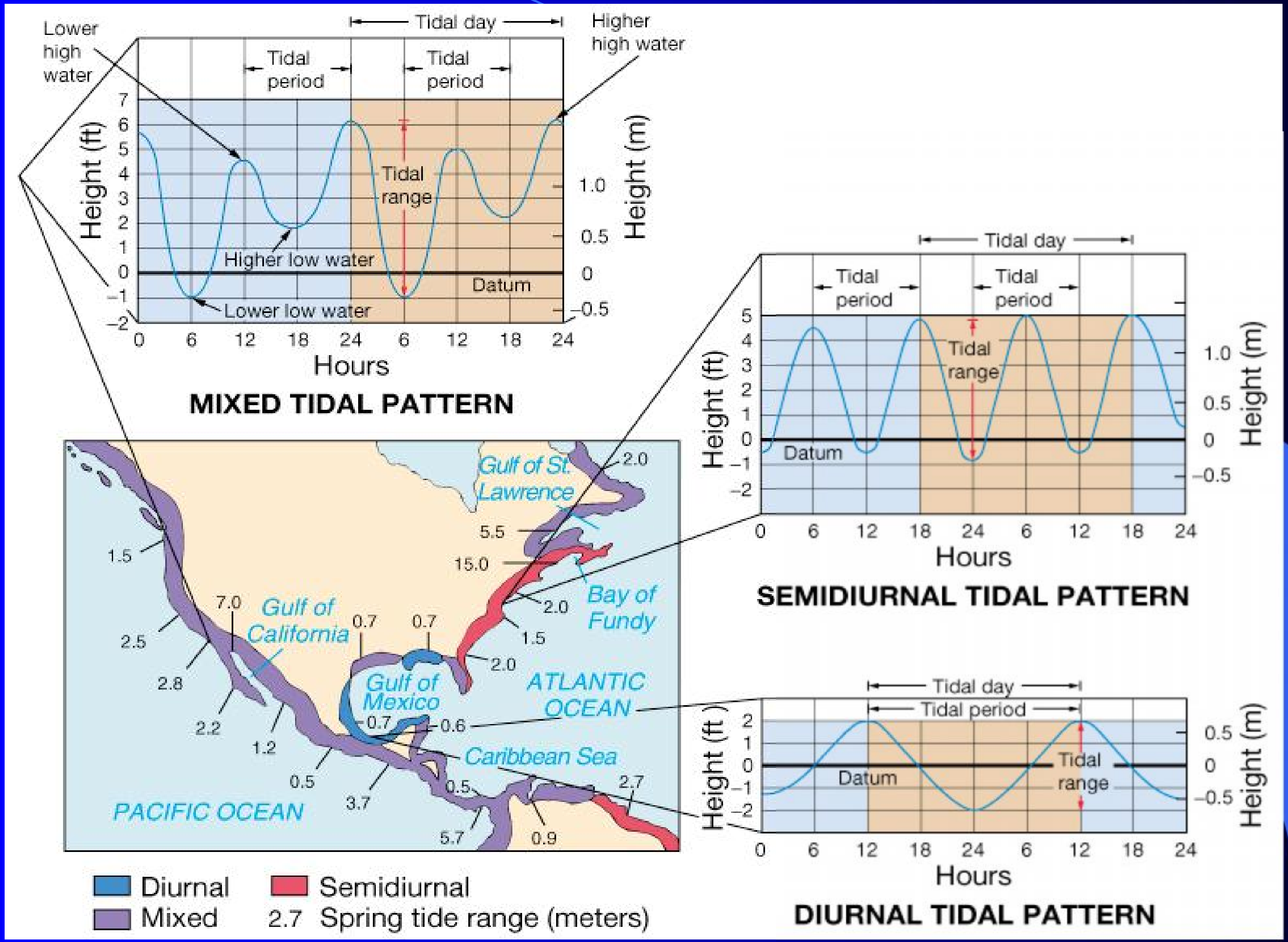
Boston, Mass. - Semidiurnal

Galvelston, Texas – Diurnal

San Francisco, CA - Mixed

Pakhoi, China - Diurnal

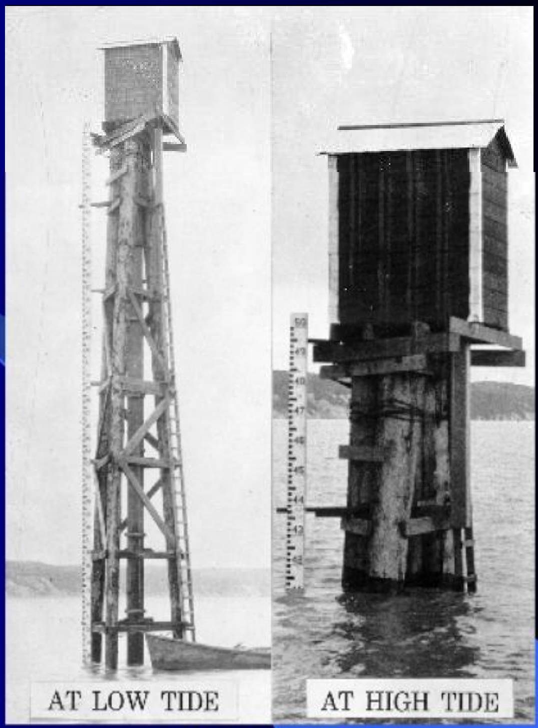
Tidal Patterns of North America



Measuring Tidal Changes

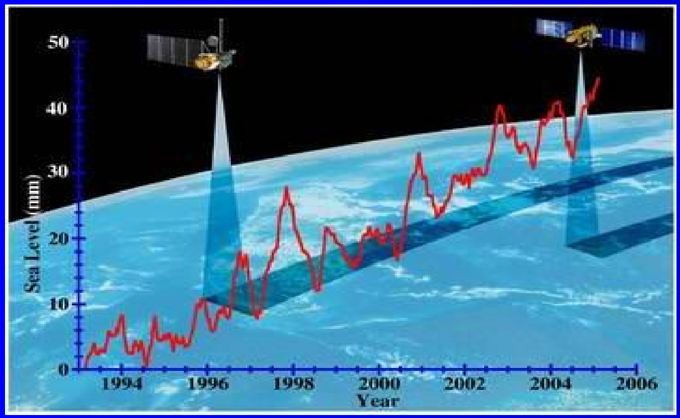
Methods

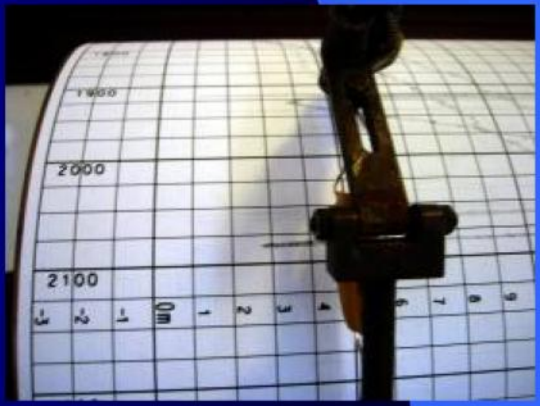
1) Tidal Staffs
2) Tidal Gauges
   - ✓ Float levels
   - ✓ Gas-purged bubblers
   - ✓ Ultrasonic altimeters
3) Bottom pressure sensors
4) Satellite altimetry



Modern methods

Old-style

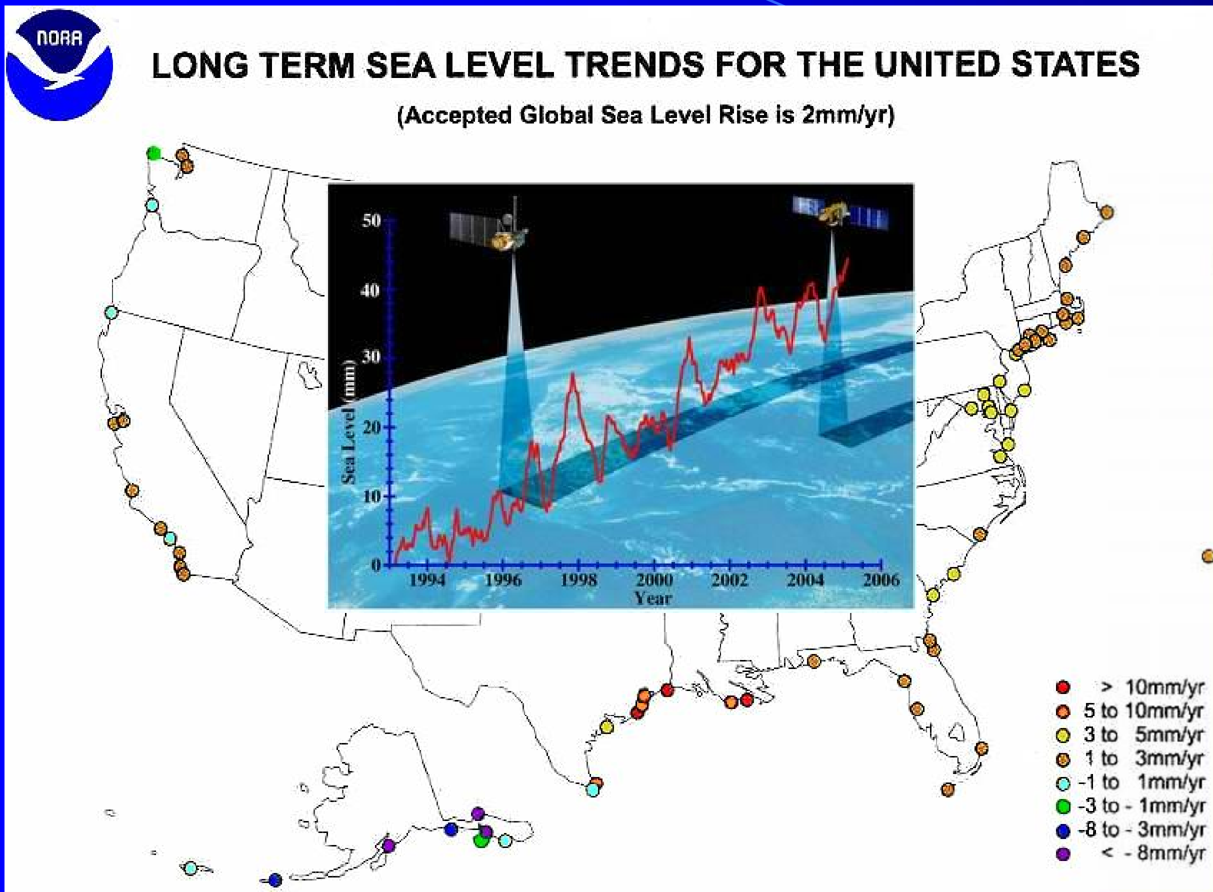


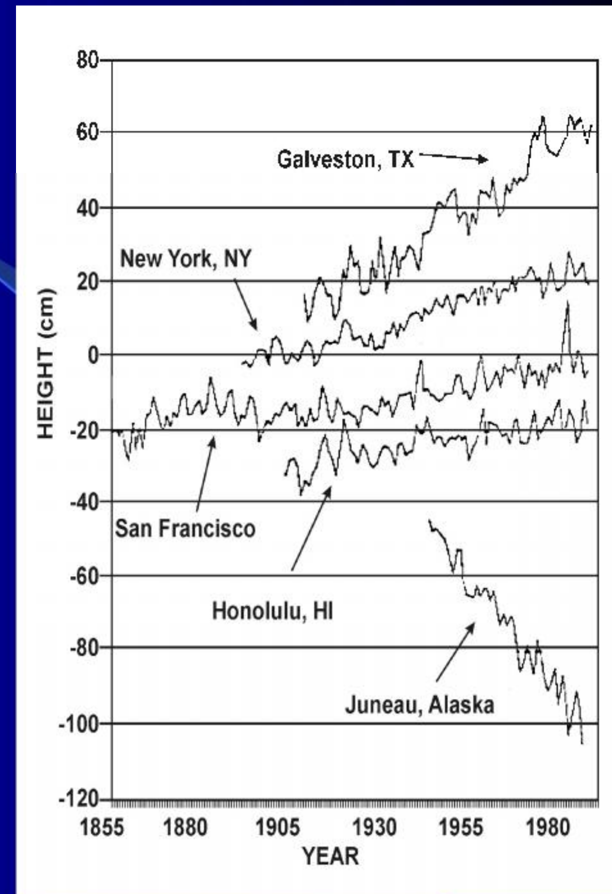


Tidal Datum

- A **tidal datum** is a base elevation in which to reckon heights and depths in terms of a phase of tide
- Tidal datums are based on a phase of the tide
  - ✓ MHW = mean high water
  - ✓ MLLW = mean low low water
- **Tide station** datums are based on a 19 year mean called an National Tidal Datum Epoch (NTDE).
- Tide stations are referenced to a bench mark system for stability checks & long term maintenance.
- **Datum applications**: Ports, chart depths , marine boundaries, hydrographic surveys, dredging, storm surge, modeling, wetland restoration, etc.

Sea Level Changes Around the USA





Questions:

1) How does changing sea level affect coastal areas over time?

2) How does changes in sea level affect tidal datum and tide prediction?

The Tidal Graph for Month of March 2017

La Jolla, Scripps Pier, California

32.8667° N, 117.2567° W

Questions:

1) What is the tidal datum for this chart?
2) What is the MLLW ?
3) How low are the minus tides?
4) When do the four Lunar phases occur in the month?

March

Day	Time (h m)	Height (ft)	Height (cm)
1 W	04:36 AM	0.5	15
	10:39 AM	4.7	143
	04:53 PM	0.2	6
	11:14 PM	4.8	146
2 Th	05:31 AM	0.6	18
	11:32 AM	4.0	122
	05:30 PM	0.7	21
	11:59 PM	4.8	146
3 F	06:40 AM	0.6	18
	12:41 PM	3.3	101
	06:15 PM	1.3	40
4 Sa	12:55 AM	4.7	143
	08:09 AM	0.6	18
	02:26 PM	2.8	85
	07:17 PM	1.8	55
5 Su ◐	02:07 AM	4.7	143
	09:49 AM	0.4	12
	04:35 PM	2.9	88
	08:54 PM	2.2	67
6 M	03:31 AM	4.8	146
	11:10 AM	-0.1	-3
	05:57 PM	3.2	98
	10:33 PM	2.1	64
7 Tu	04:48 AM	5.0	152
	12:08 PM	-0.5	-15
	06:46 PM	3.7	113
	11:44 PM	1.8	55
8 W	05:50 AM	5.3	162
	12:55 PM	-0.8	-24
	07:24 PM	4.0	122
9 Th	12:38 AM	1.4	43
	06:42 AM	5.5	168
	01:34 PM	-0.9	-27
	07:57 PM	4.3	131
10 F	01:23 AM	1.0	30
	07:26 AM	5.6	171
	02:09 PM	-0.9	-27
	08:27 PM	4.5	137
11 Sa	02:04 AM	0.7	21
	08:07 AM	5.6	171
	02:41 PM	-0.8	-24
	08:56 PM	4.7	143
12 Su ○	03:42 AM	0.5	15
	09:45 AM	5.4	165
	04:10 PM	-0.5	-15
	10:24 PM	4.7	143
13 M	04:18 AM	0.4	12
	10:21 AM	5.0	152
	04:38 PM	-0.1	-3
	10:51 PM	4.7	143
14 Tu	04:55 AM	0.4	12
	10:57 AM	4.6	140
	05:04 PM	0.3	9
	11:18 PM	4.7	143
15 W	05:32 AM	0.5	15
	11:33 AM	4.1	125
	05:29 PM	0.8	24
	11:45 PM	4.5	137
16 Th	06:13 AM	0.6	18
	12:13 PM	3.6	110
	05:52 PM	1.2	37
17 F	12:15 AM	4.4	134
	07:02 AM	0.9	27
	01:02 PM	3.1	94
	06:15 PM	1.7	52
18 Sa	12:48 AM	4.1	125
	08:06 AM	1.1	34
	02:19 PM	2.6	79
	06:39 PM	2.1	64
19 Su	01:35 AM	3.9	119
	09:39 AM	1.1	34
	05:07 PM	2.5	76
	07:12 PM	2.5	76
20 M ◑	02:51 AM	3.8	116
	11:17 AM	0.9	27
	07:02 PM	2.8	85
	10:03 PM	2.7	82
21 Tu	04:31 AM	3.8	116
	12:21 PM	0.6	18
	07:25 PM	3.1	94
	11:50 PM	2.5	76
22 W	05:46 AM	4.1	125
	01:03 PM	0.2	6
	07:46 PM	3.4	104
23 Th	12:43 AM	2.1	64
	06:39 AM	4.4	134
	01:38 PM	-0.1	-3
	08:06 PM	3.7	113
24 F	01:23 AM	1.6	49
	07:23 AM	4.8	146
	02:09 PM	-0.3	-9
	08:29 PM	4.1	125
25 Sa	02:00 AM	1.1	34
	08:03 AM	5.1	155
	02:39 PM	-0.5	-15
	08:54 PM	4.4	134
26 Su	02:37 AM	0.6	18
	08:42 AM	5.3	162
	03:09 PM	-0.5	-15
	09:21 PM	4.8	146
27 M	03:16 AM	0.2	6
	09:23 AM	5.3	162
	03:40 PM	-0.4	-12
	09:51 PM	5.1	155
28 Tu ●	03:57 AM	-0.2	-6
	10:05 AM	5.1	155
	04:13 PM	-0.2	-6
	10:23 PM	5.3	162
29 W	04:41 AM	-0.4	-12
	10:50 AM	4.8	146
	04:46 PM	0.2	6
	10:59 PM	5.5	168
30 Th	05:30 AM	-0.5	-15
	11:41 AM	4.3	131
	05:23 PM	0.7	21
	11:39 PM	5.4	165
31 F	06:25 AM	-0.4	-12
	12:41 PM	3.7	113
	06:03 PM	1.2	37

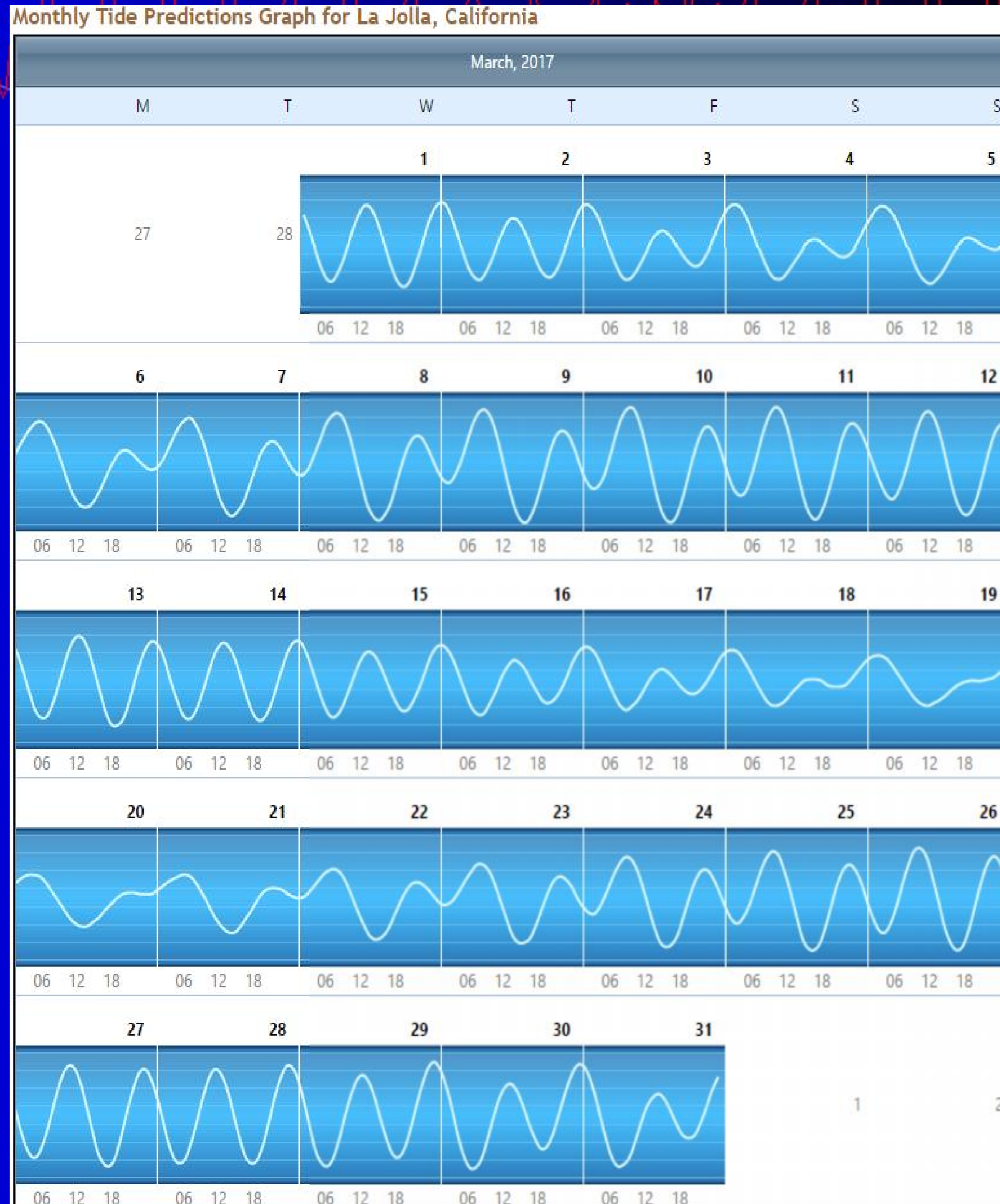
The Tidal Graph for Month of March 2017

Questions:

1) Which type of tide does this graph illustrate?

2) When do the neap tides occur?

3) When do the spring tides occur?

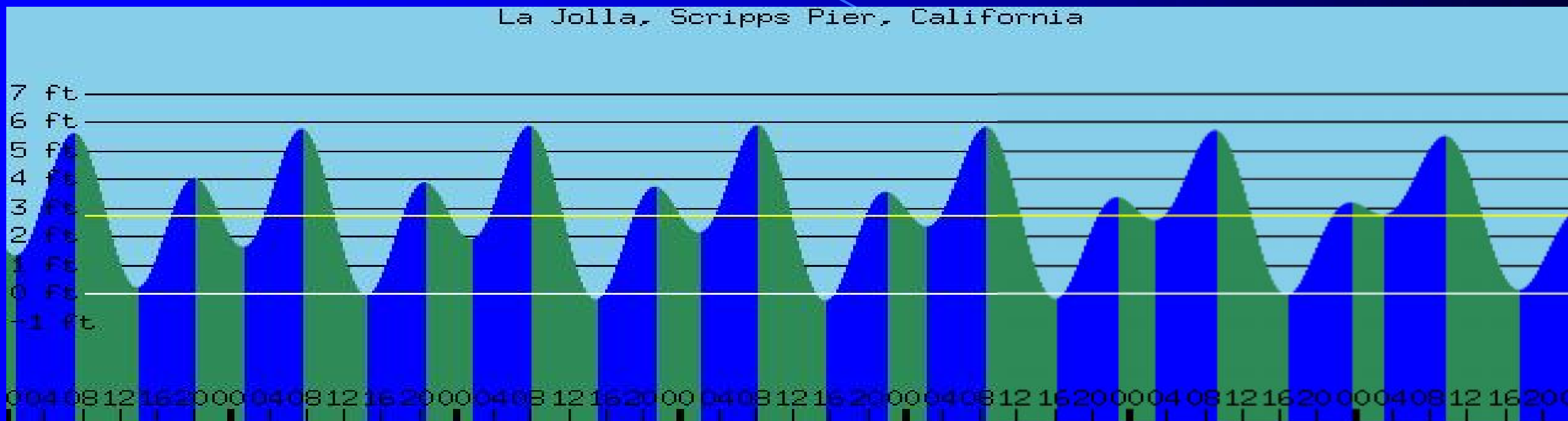


March 2014 Tides – San Diego

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
						1 5.93H 5.25H 0.2L -0.91L
2 5.51H 5.33H 0.02L -0.49L	**3** 4.91H 5.26H 0.02L 0.05L	**4** 4.22H 5.06H 0.19L 0.66L	**5** 3.52H 0.45L 1.29L	**6** 4.75H 2.95H 0.73L 1.86L	**7** 4.42H 2.71H 0.86L 2.33L	**8** 4.18H 2.92H 0.75L 2.53L
9 4.15H 3.23H 0.49L 2.37L	**10** 4.31H 3.49H 0.24L	**11** 4.53H 3.73H 2.06L 0.05L	**12** 4.74H 3.96H 1.71L -0.08L	**13** 4.9H 4.19H 1.36L -0.15L	**14** 4.98H 4.43H 1.03L -0.16L	**15** 4.97H 4.65H 0.73L -0.09L
16 4.86H 4.83H 0.48L 0.05L	**17** 4.64H 4.96H 0.3L 0.27L	**18** 4.32H 5.03H 0.2L 0.56L	**19** 3.91H 5.02H 0.19L 0.92L	**20** 3.44H 0.26L 1.32L	**21** 4.93H 2.98H 0.39L 1.74L	**22** 4.76H 2.69H 0.47L 2.15L
23 4.58H 2.82H 0.39L 2.43L	**24** 4.5H 3.23H 0.1L 2.28L	**25** 4.65H 3.72H -0.24L	**26** 4.93H 4.22H 1.77L -0.51L	**27** 5.19H 4.7H 1.13L -0.65L	**28** 5.32H 5.12H 0.5L -0.63L	**29** 5.29H 5.44H -0.03L -0.46L
30 5.09H 5.61H -0.41L -0.16L	**31** 4.74H 5.61H -0.59L 0.24L					

Tide Charts

La Jolla, Scripps Pier, California 32.8667° N, 117.2567° W

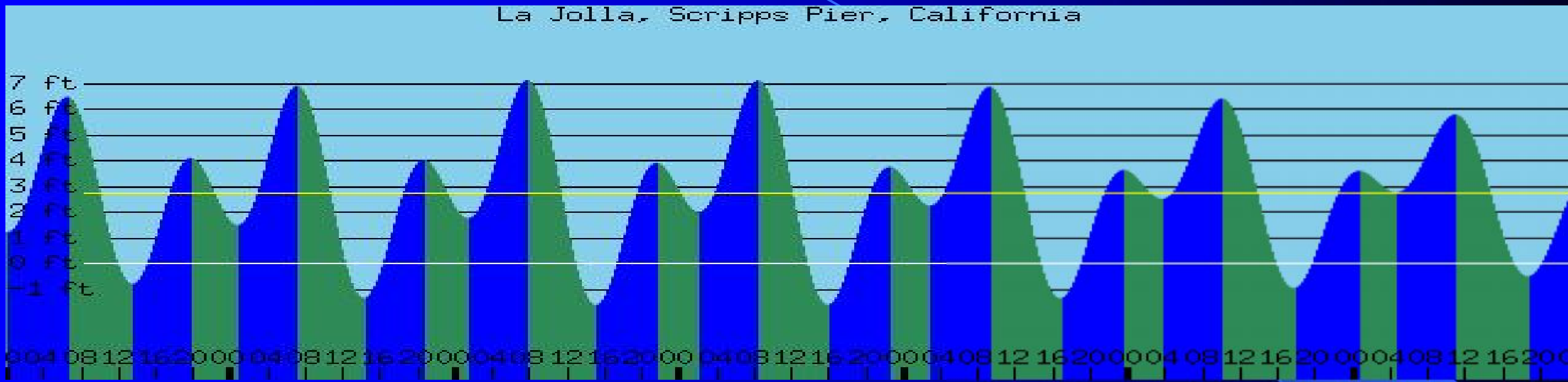


7 November 2007 - 13 November 2007

2007-11-07	00:49 PST	1.33 feet	Low Tide
2007-11-07	07:06 PST	5.61 feet	High Tide
2007-11-07	13:51 PST	0.22 feet	Low Tide
2007-11-07	19:58 PST	4.04 feet	High Tide
2007-11-08	01:11 PST	1.63 feet	Low Tide
2007-11-08	07:26 PST	5.76 feet	High Tide
2007-11-08	14:21 PST	-0.05 feet	Low Tide
2007-11-08	20:35 PST	3.89 feet	High Tide
2007-11-09	01:32 PST	1.90 feet	Low Tide
2007-11-09	07:47 PST	5.85 feet	High Tide
2007-11-09	14:52 PST	-0.20 feet	Low Tide
2007-11-09	21:13 PST	3.73 feet	High Tide
2007-11-10	01:54 PST	2.13 feet	Low Tide
2007-11-10	08:10 PST	5.87 feet	High Tide
2007-11-10	15:25 PST	-0.25 feet	Low Tide
2007-11-10	21:53 PST	3.56 feet	HighTide
2007-11-11	02:15 PST	2.35 feet	Low Tide
2007-11-11	08:35 PST	5.82 feet	High Tide
2007-11-11	16:01 PST	-0.19 feet	Low Tide
2007-11-11	22:38 PST	3.36 feet	High Tide
2007-11-12	02:37 PST	2.55 feet	Low Tide
2007-11-12	09:04 PST	5.69 feet	High Tide
2007-11-12	16:41 PST	-0.05 feet	Low Tide
2007-11-12	23:33 PST	3.18 feet	High Tide
2007-11-13	02:57 PST	2.75 feet	Low Tide
2007-11-13	09:36 PST	5.50 feet	High Tide
2007-11-13	17:29 PST	0.13 feet	Low Tide

Tide Charts

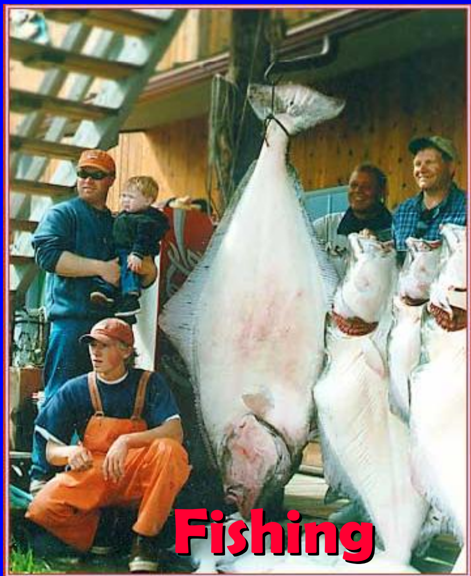
La Jolla, Scripps Pier, California 32.8667° N, 117.2567° W

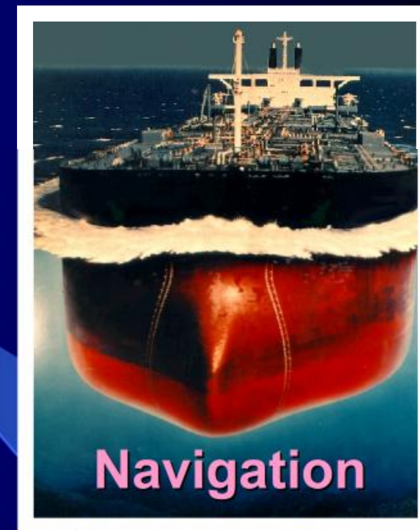


22 November 2007 - 28 November 2007

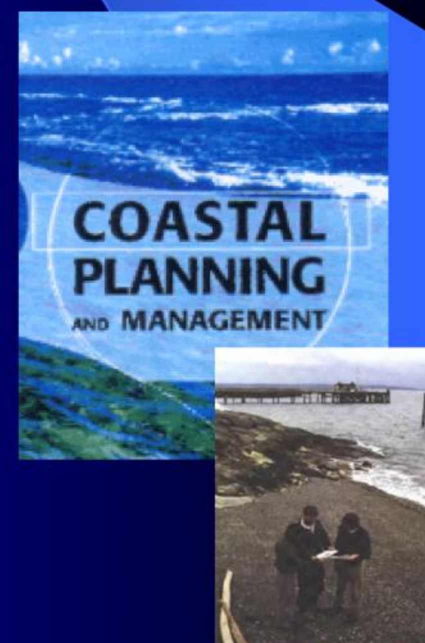
2007-11-22	00:04 PST	1.22 feet Low Tide
2007-11-22	06:28 PST	6.47 feet High Tide
2007-11-22	13:28 PST	-0.79 feet Low Tide
2007-11-22	19:42 PST	4.10 feet High Tide
2007-11-23	00:42 PST	1.49 feet Low Tide
2007-11-23	07:05 PST	6.89 feet High Tide
2007-11-23	14:14 PST	-1.34 feet Low Tide
2007-11-23	20:37 PST	4.02 feet High Tide
2007-11-24	01:22 PST	1.75 feet Low Tide
2007-11-24	07:44 PST	7.12 feet High Tide
2007-11-24	15:02 PST	-1.61 feet Low Tide
2007-11-24	21:32 PST	3.90 feet High Tide
2007-11-25	02:03 PST	2.01 feet Low Tide
2007-11-25	08:26 PST	7.11 feet High Tide
2007-11-25	15:52 PST	-1.60 feet Low Tide
2007-11-25	22:30 PST	3.75 feet High Tide
2007-11-26	02:47 PST	2.25 feet Low Tide
2007-11-26	09:12 PST	6.86 feet High Tide
2007-11-26	16:44 PST	-1.35 feet Low Tide
2007-11-26	23:31 PST	3.63 feet High Tide
2007-11-27	03:37 PST	2.50 feet Low Tide
2007-11-27	10:01 PST	6.40 feet High Tide
2007-11-27	17:40 PST	-0.96 feet Low Tide
2007-11-28	00:40 PST	3.59 feet High Tide
2007-11-28	04:36 PST	2.76 feet Low Tide
2007-11-28	10:55 PST	5.78 feet High Tide
2007-11-28	18:39 PST	-0.50 feet Low Tide

Applications of Tide Prediction





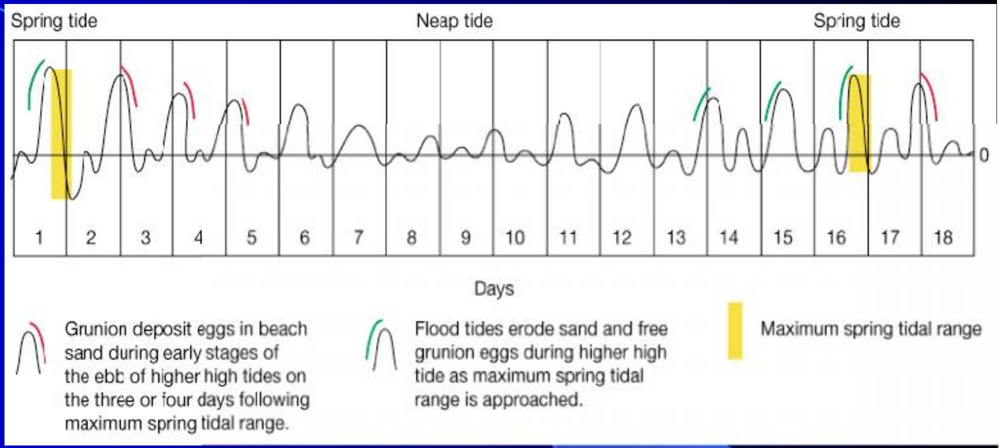
Beachg



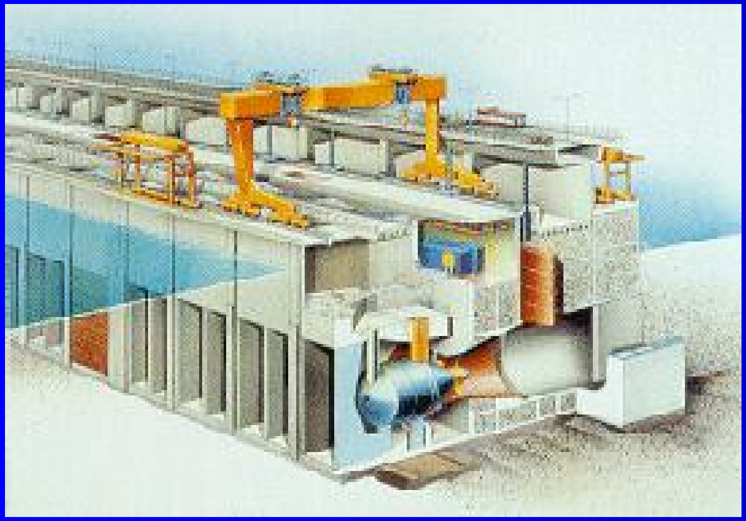
Grunion and the Tides

Grunion Facts:

- Grunion are the only fish that come completely out of water to spawn
- Spawning cycles are timed precisely with the tides
- Grunion leave the water at night to spawn on the beach in the spring and summer months two to six nights after the full and new moons
- Spawning begins after high tide and continues for several hours.



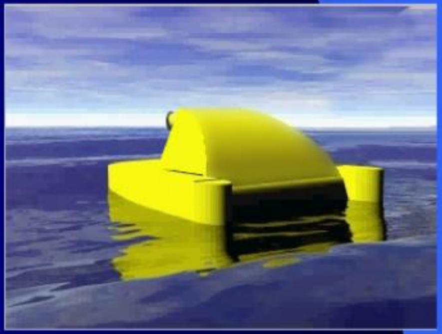
Energy From Tides - Today



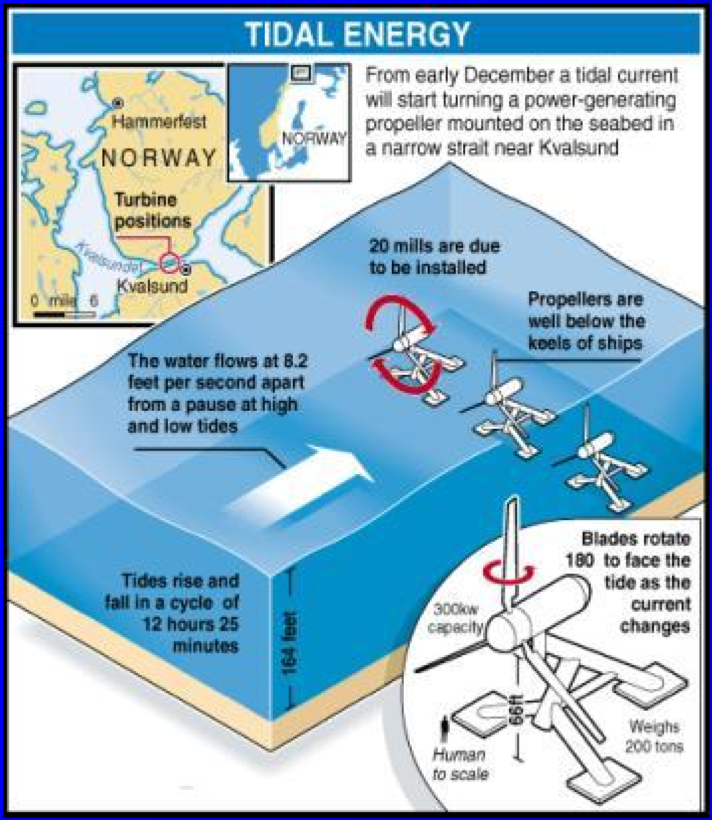
Tidal Bore Turbines

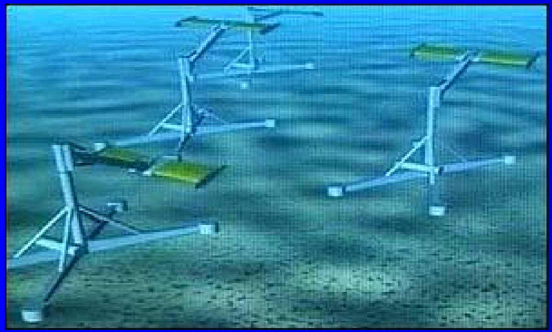
La Rance, France

Severn River, France



Energy From Tides - Future





Tidal Conclusions

- Tides are extremely swift, very long-wavelength, shallow-water waves
- Tides are periodic short-term changes in sea level at a particular place caused by the gravitational force of the moon and sun, and the motion of the Earth
- The moon's influence is twice as great as that of the sun's
- Gravity's attractive force and inertia's flinging-away force combine to produce two ocean tidal bulges
- The Earth rotating underneath the tidal bulges causes tides
- The equilibrium theory of tides only takes into account gravitational and rotational affects under equilibrium conditions without regard to ocean basin shape, water depth, ocean inertia, Coriolis effect, nor sea bottom friction drag
- The dynamic theory of tides is a much more robust prediction model that also takes account all those factors left out of the equilibrium theory (listed above)
- Tidal patterns take three forms worldwide: diurnal, semidiurnal, and mixed
- Tides in each ocean basin form a rocking-rotary cycle around *amphidromic* "no tide" points – counterclockwise in N. Hemi, clockwise in the S. Hemi

Class Discussion

Surf fishing at Torrey Pines State Beach