How the Earth's Rotation Affects the Weather?

by
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Meteo France
Toulouse

Original “Zapytaj Fizyka” Question:

What happens to the weather when the Earth begins to rotate slower/faster?

Weather?

Question of Taxonomy:

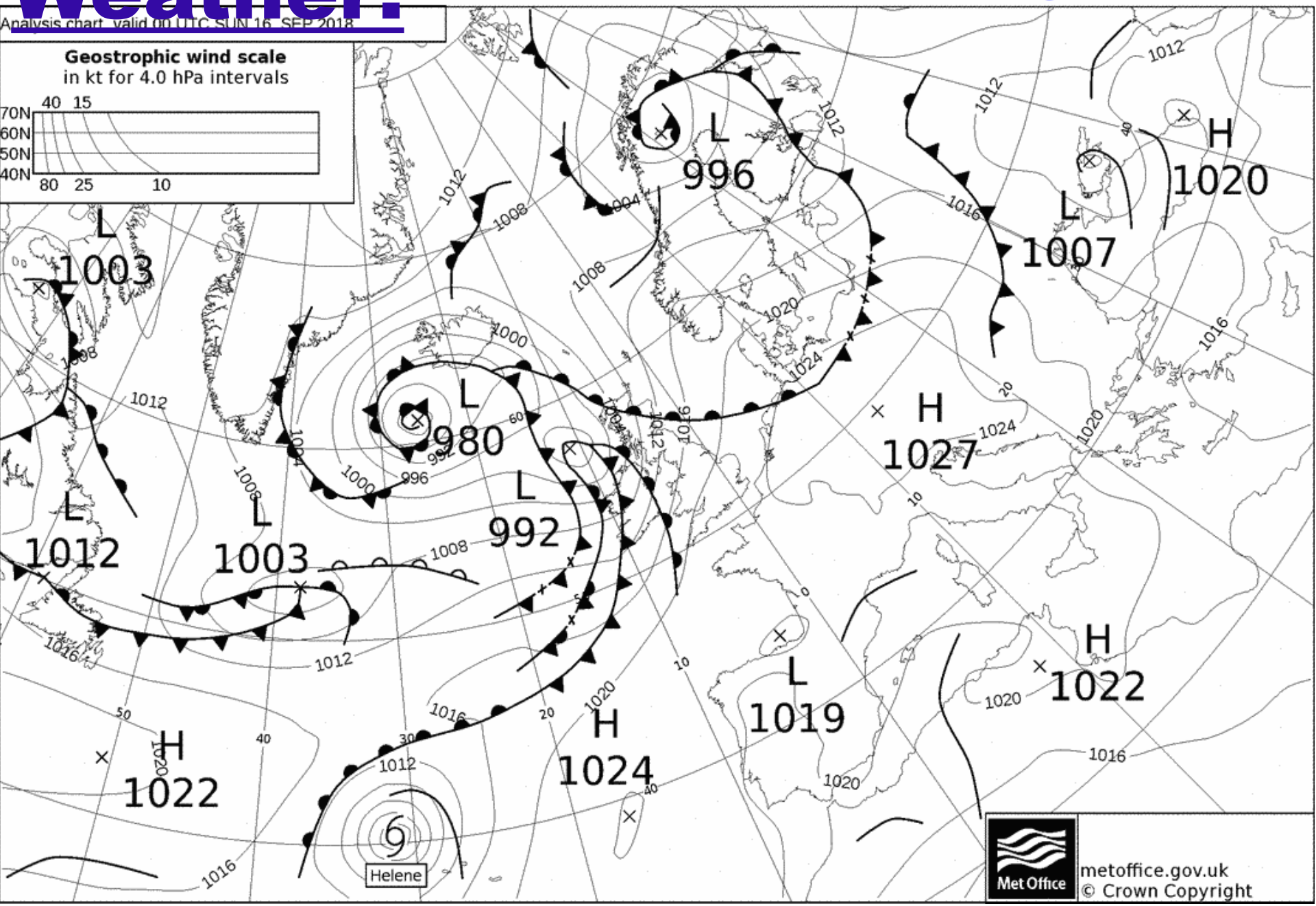
cf.,
M. Foucaullt:
Les Mots et les Choses

Weather?

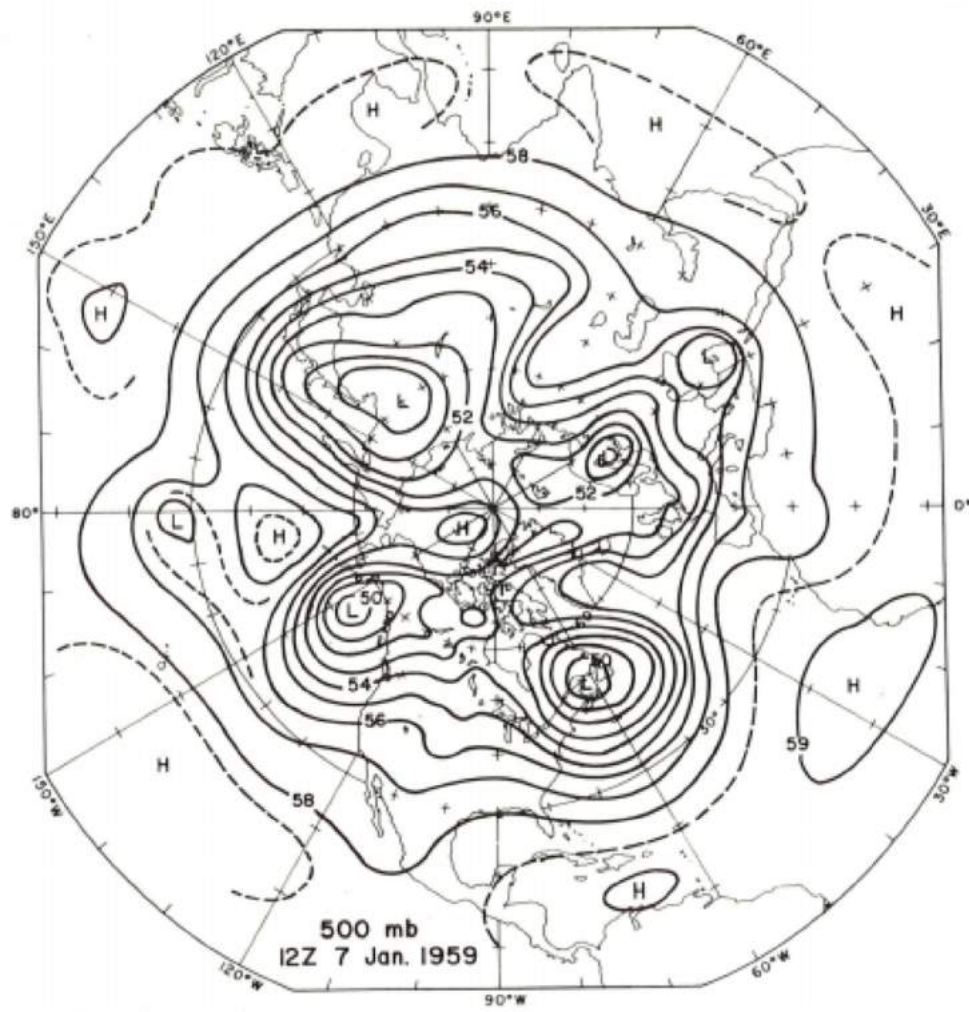
Weather?

Weather?

Weather:



Weather (Global View):



(Palmén and Newton 1969)

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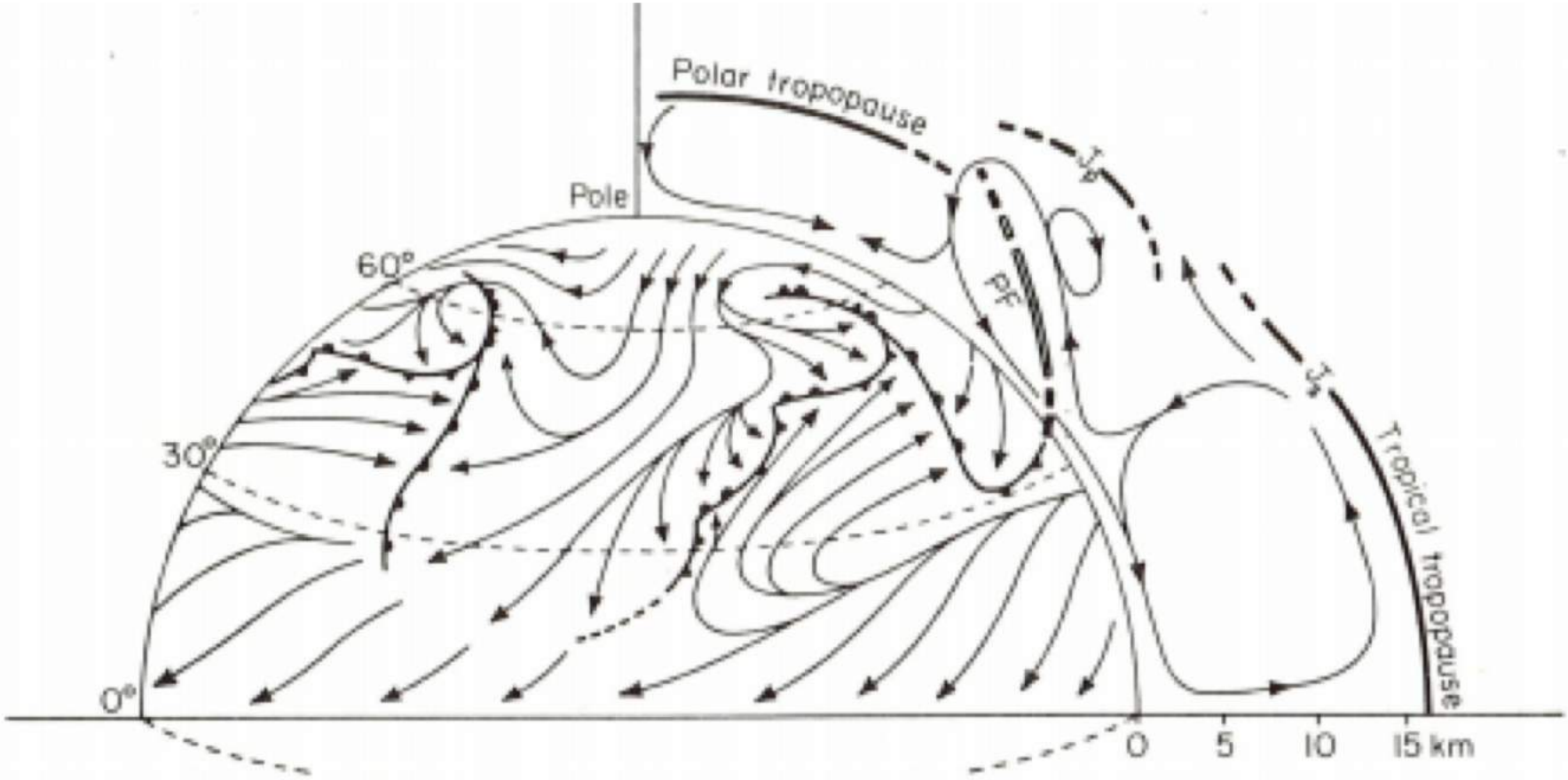

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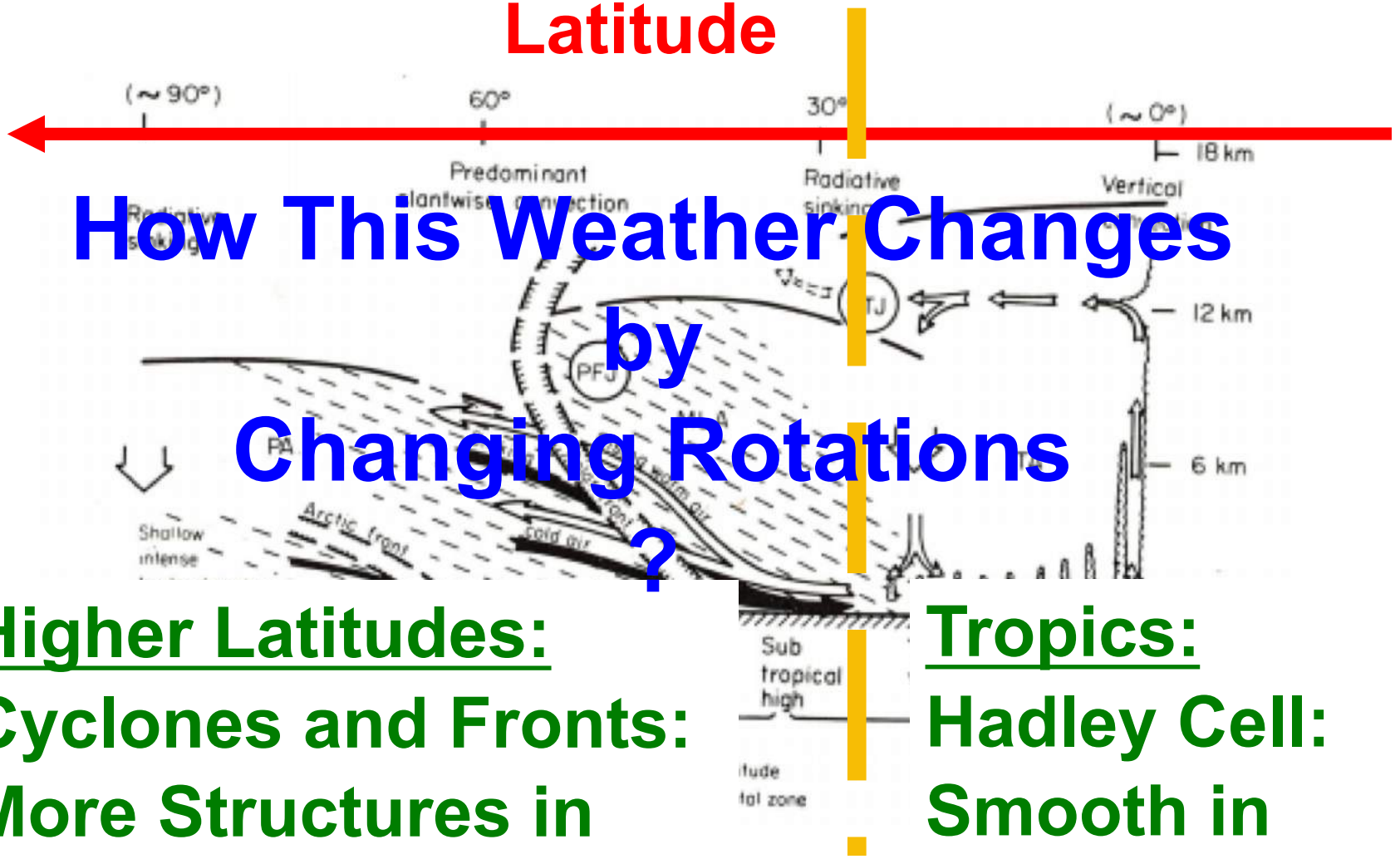


How This Weather Changes by Changing Rotations ?

Higher Latitudes:

Cyclones and Fronts:

More Structures in Longitude

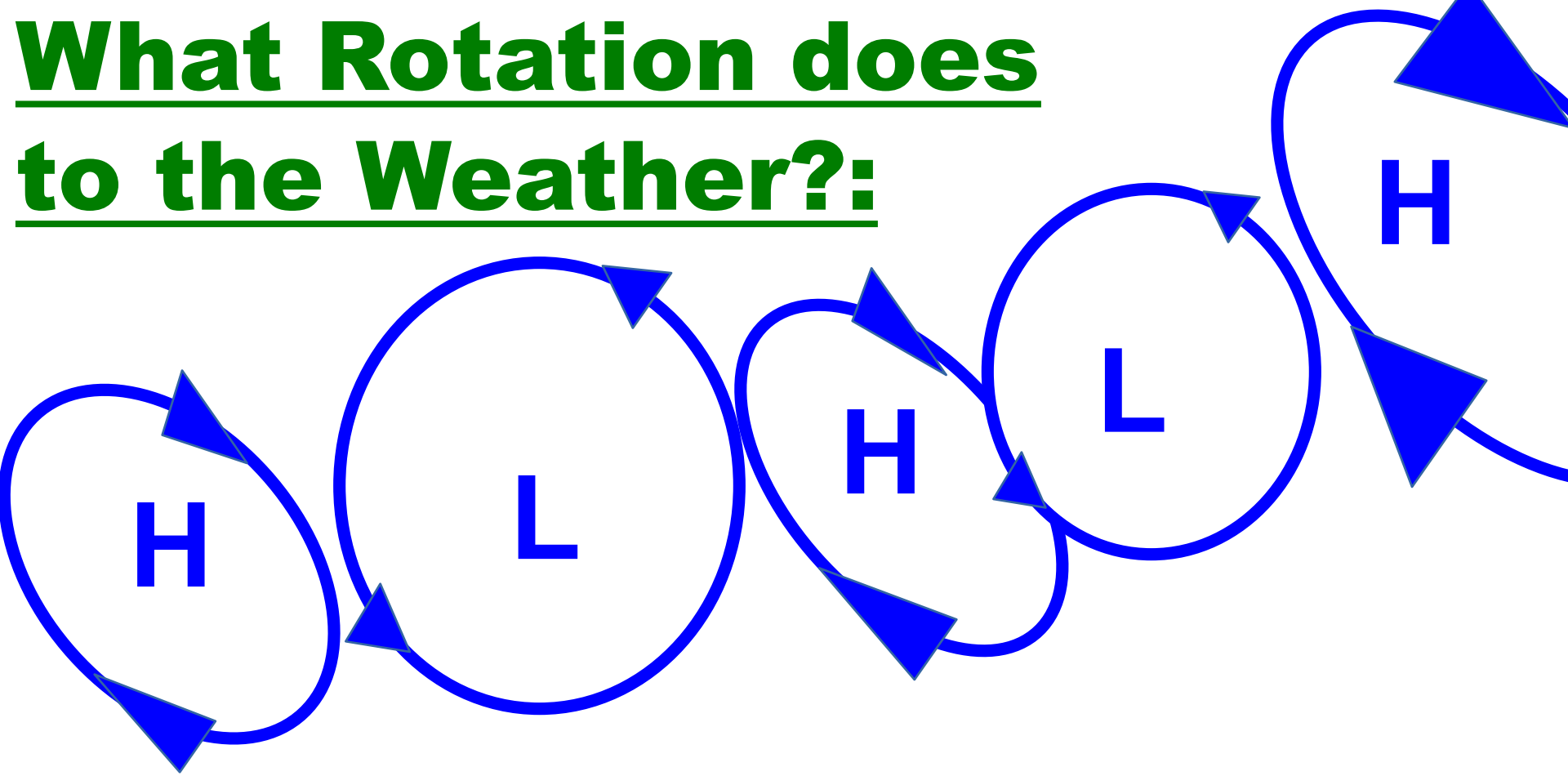
Tropics:

Hadley Cell:

Smooth in Longitude

(Palmén and Newton 1969)

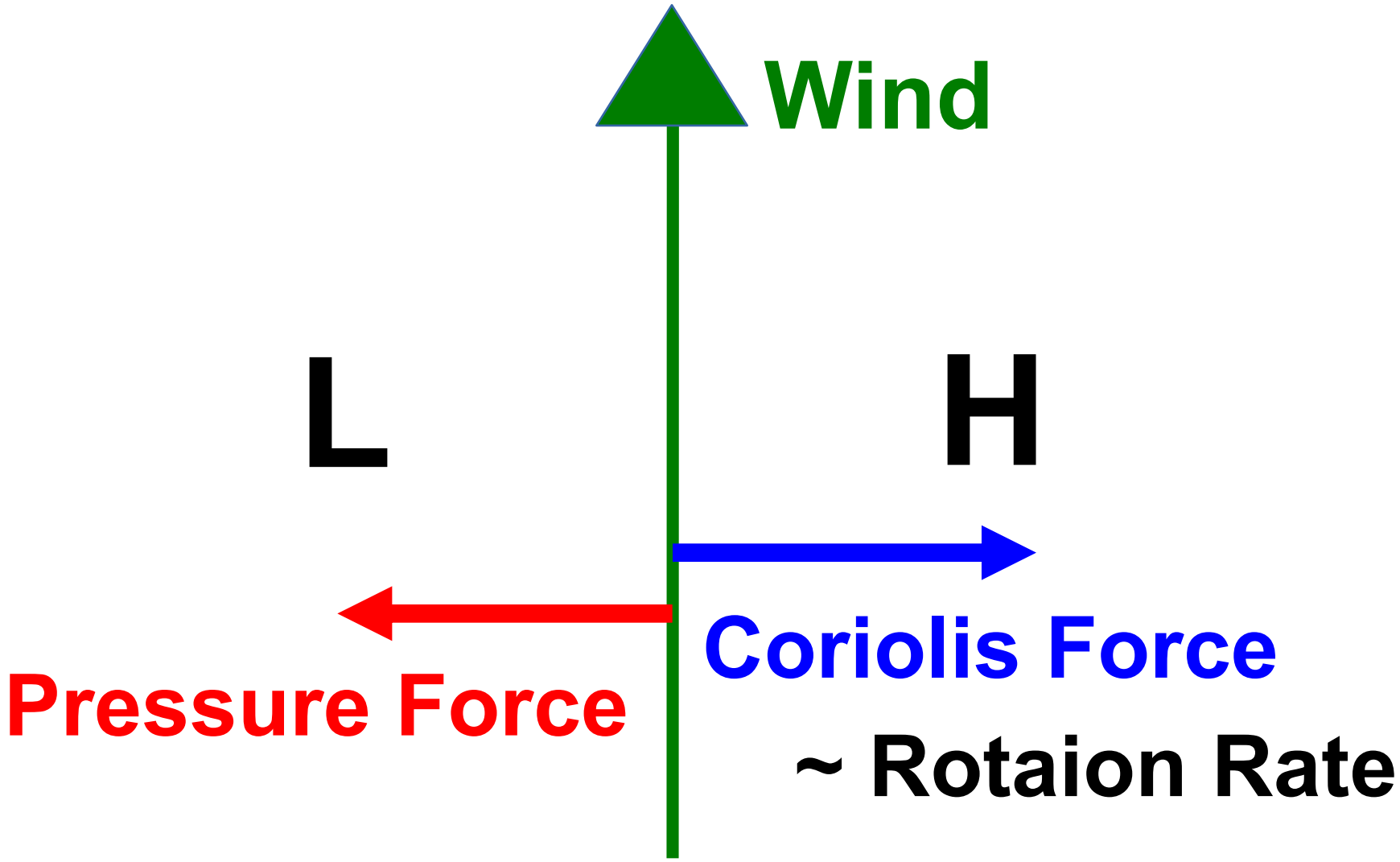
What Rotation does to the Weather?:



Winds~Pressure Lines:

Coriolis Force

What Rotation does to the Weather?:



Q: What happens to the weather when the Earth begins to rotate slower/faster?

Three Approaches:

1. Laboratory Experiments

2. Planetary Atmospheres

3. Theory: Explanations

Laboratory Experiment: Rotating Tank:

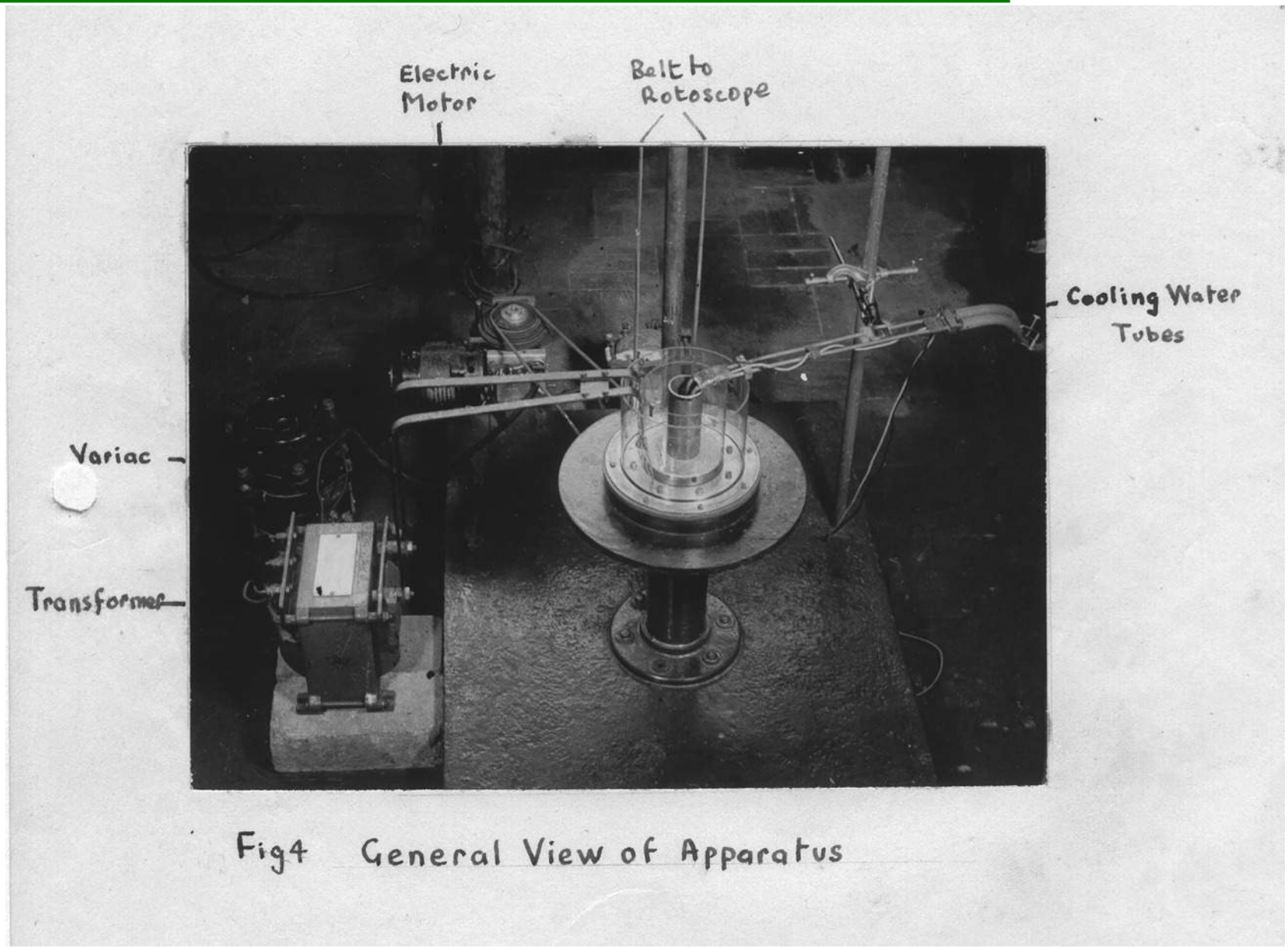
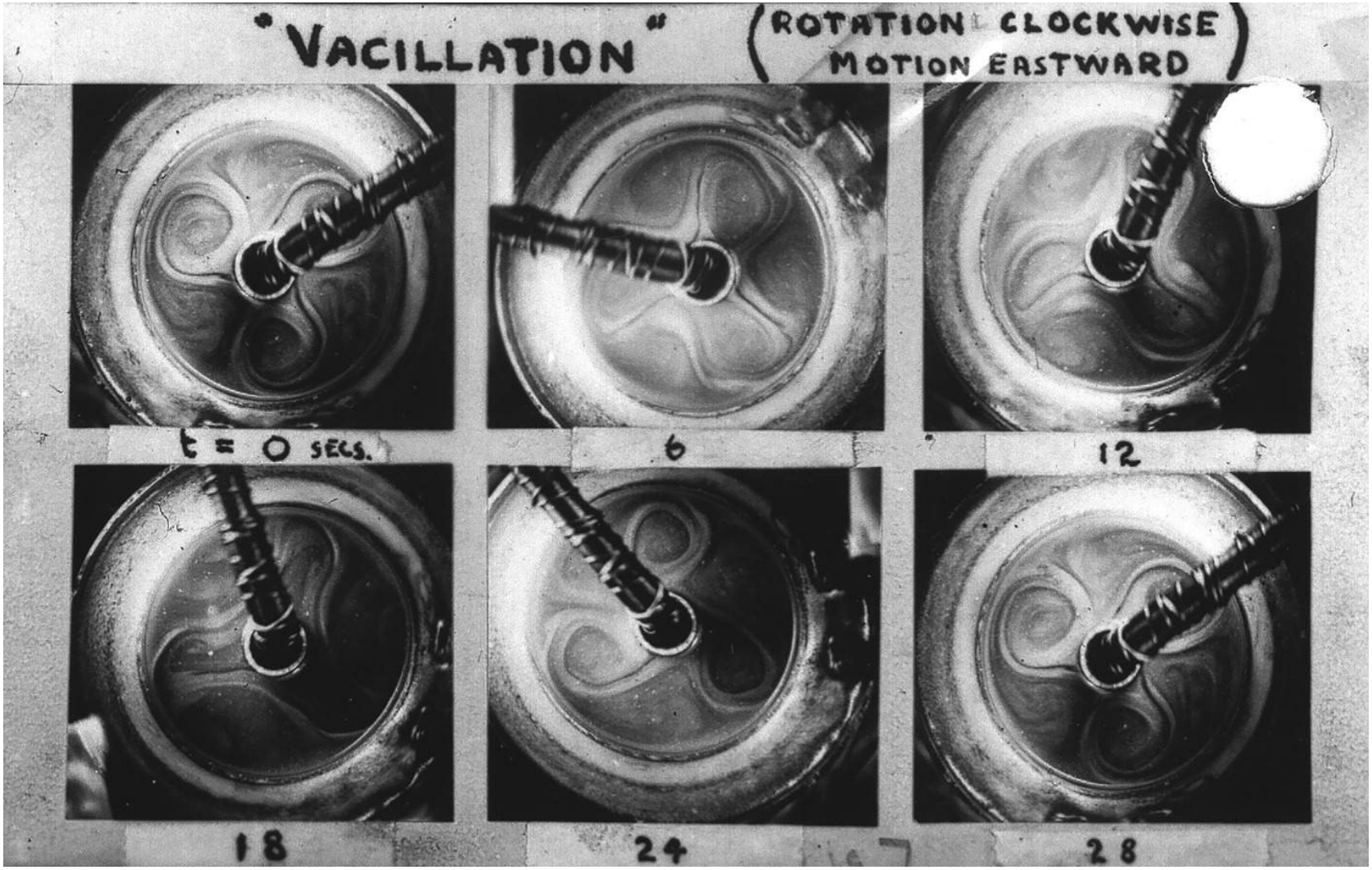


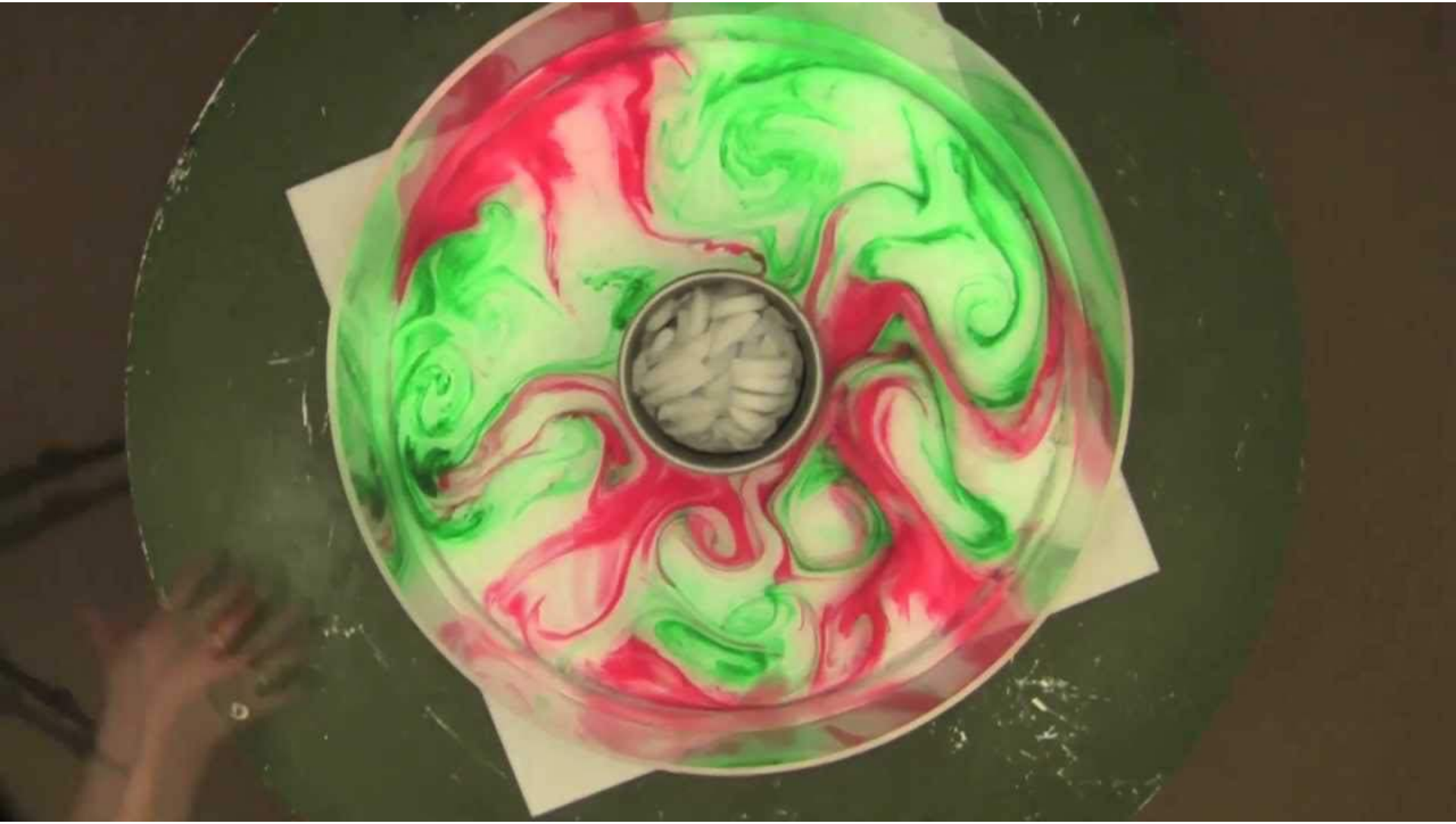
Fig4 General View of Apparatus

(Hide 1958)

Laboratory Experiment: Snap Shots:



(Hide 1958)




Exploring the Earth
Scientist
NASA

Laboratory Experiment: Rotating Tank:

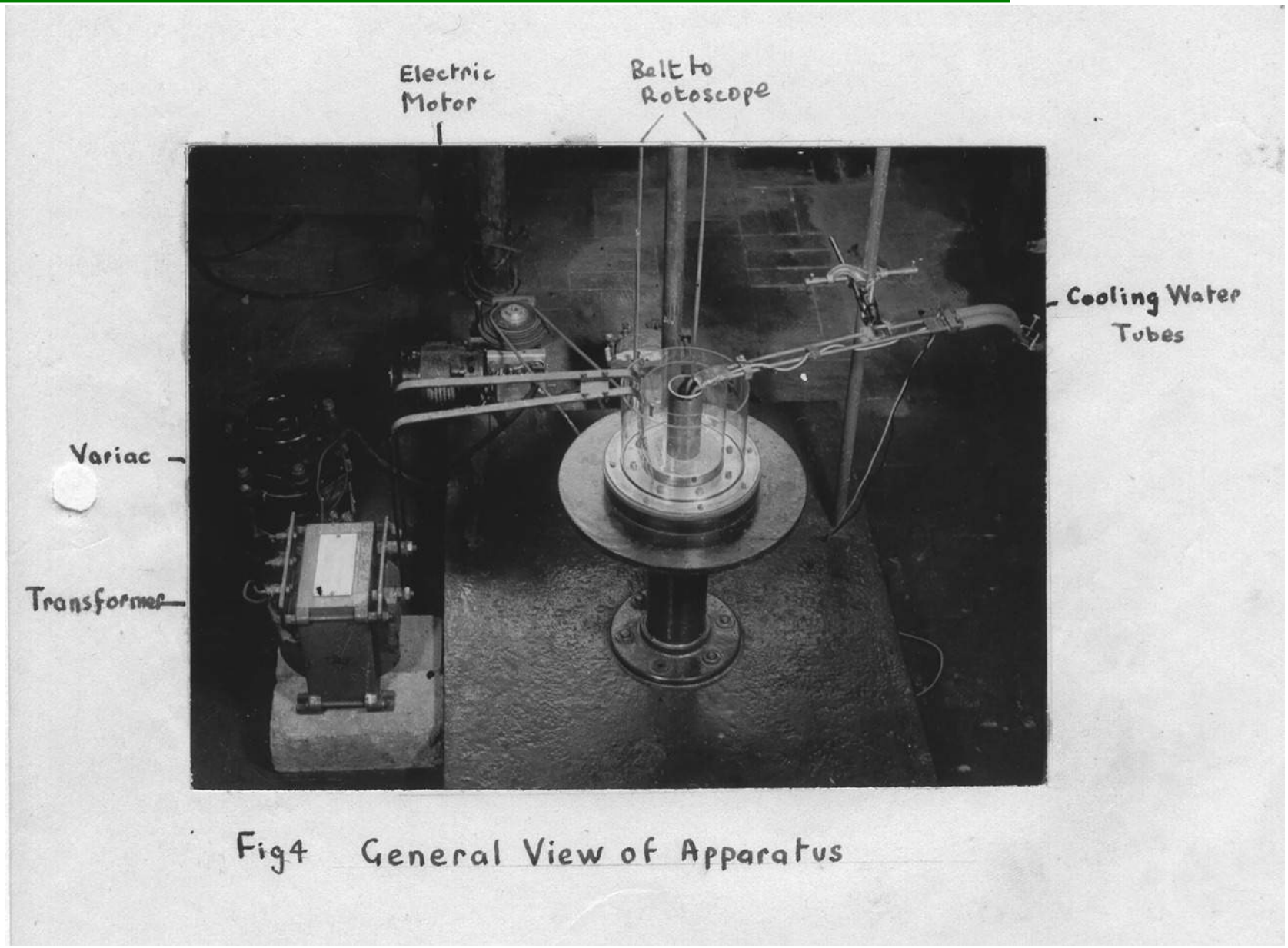
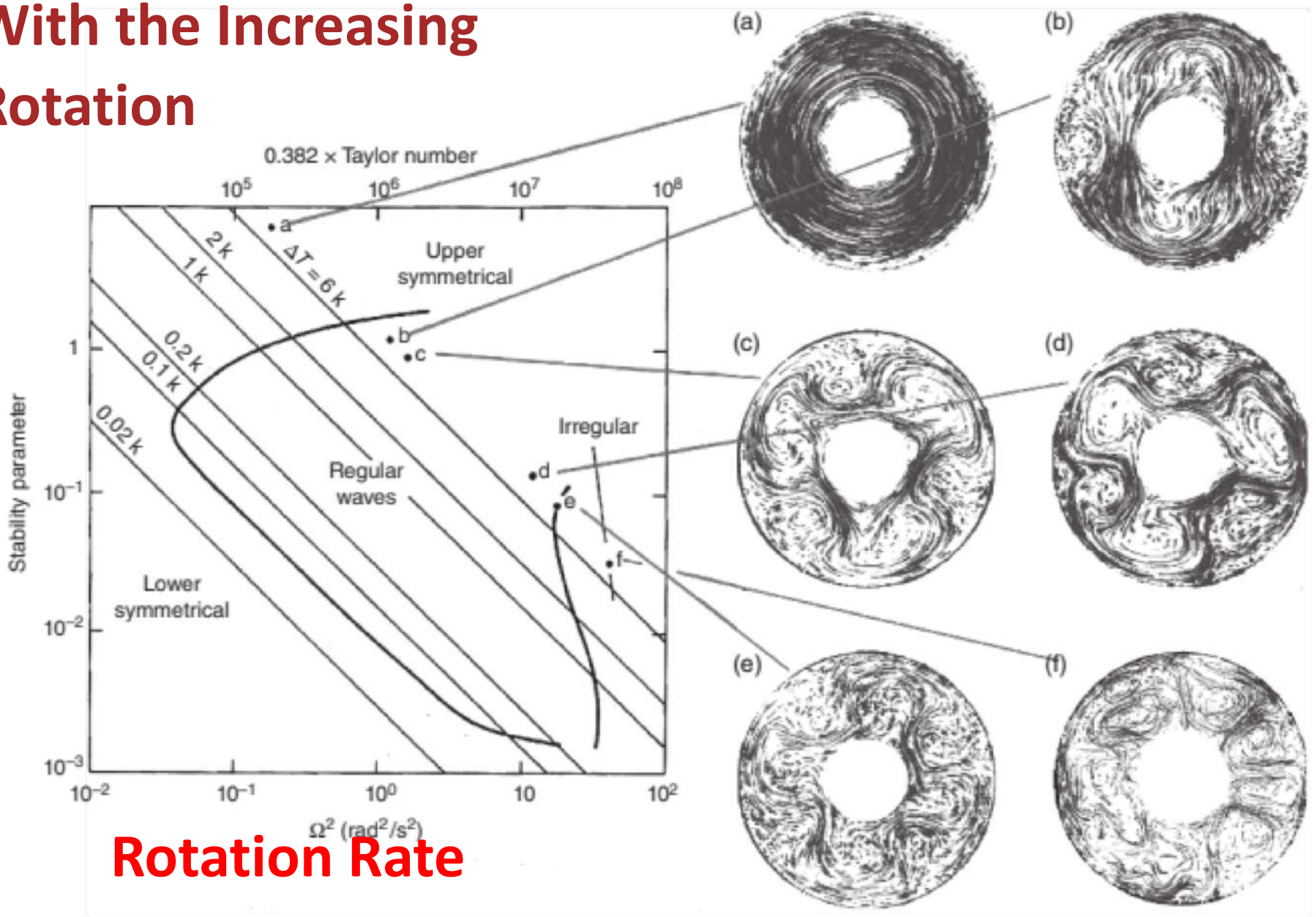


Fig4 General View of Apparatus

(Hide 1958)

Rotating Tank Experiment:

With the Increasing Rotation



Rotation Rate

Rotating Tank Experiment:

Summary of the Results:

With Very Slow Rotations:

Smooth in Longitudinal direction: Hadley Cell

With Increasing Rotations:

Breaks down into

Eddies in Longitudinal direction:

Weather of Cyclones and Fronts

With Further Increase of Rotations:

Weather Pattern becomes increasingly Irregular

Planets with Atmospheres

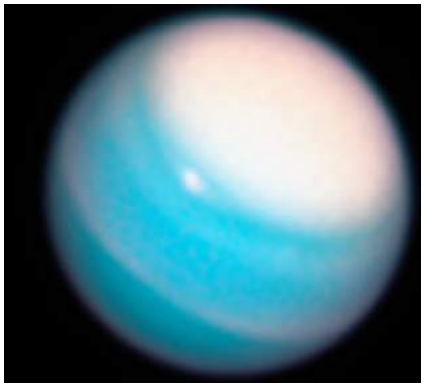
Venus

Earth

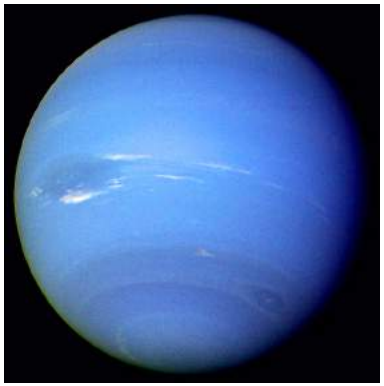
Mars

Jupiter

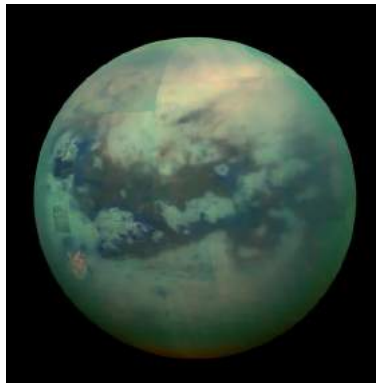
Saturn



Uranus

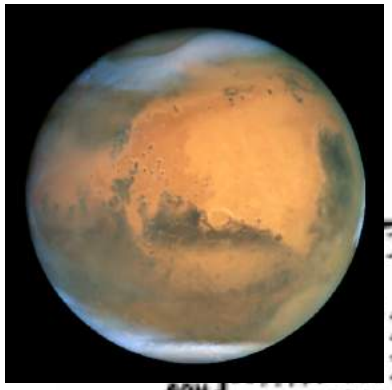


Neptune

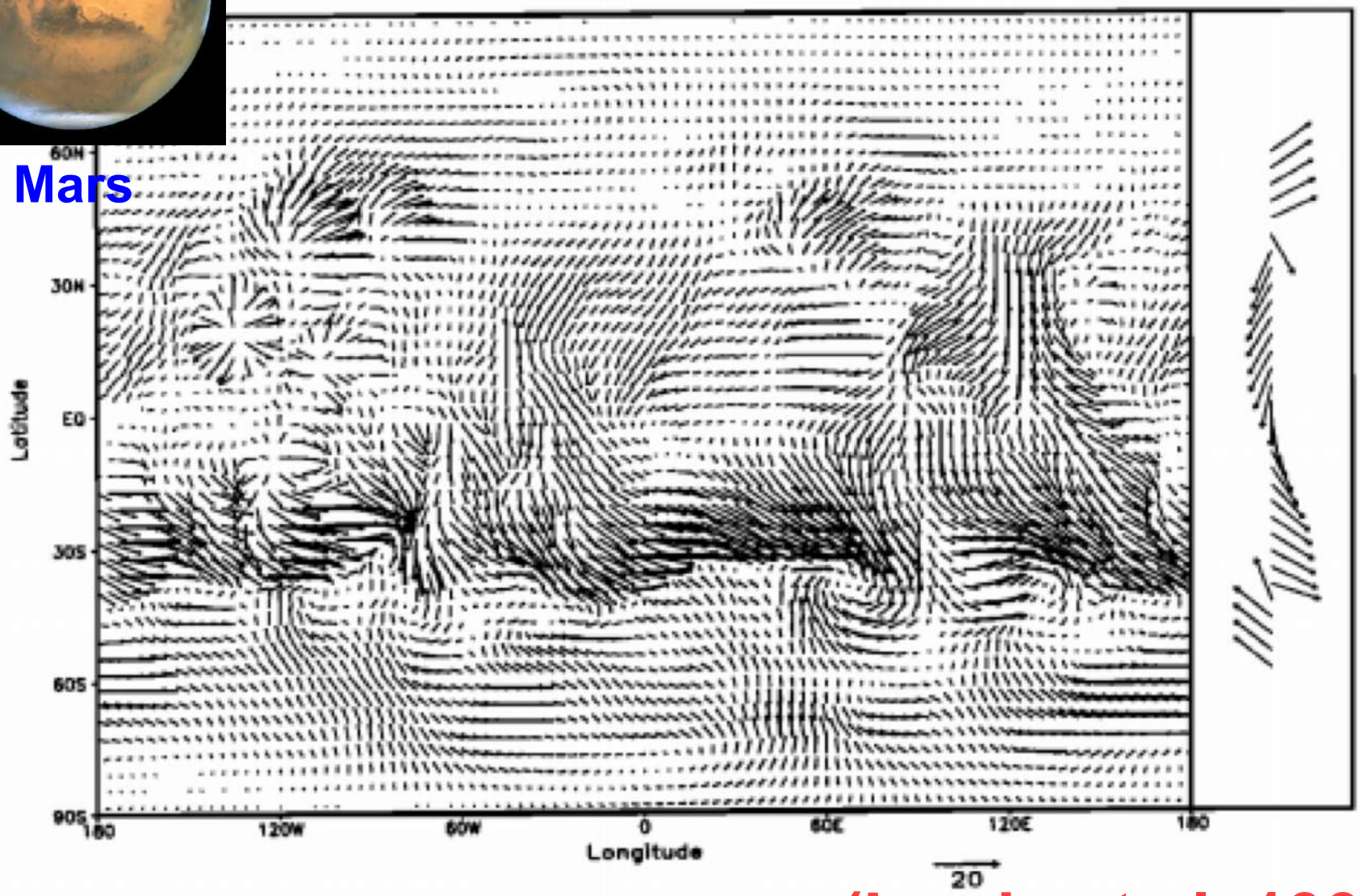


Titan (Saturn's Satellite)

Surface Winds of Mars

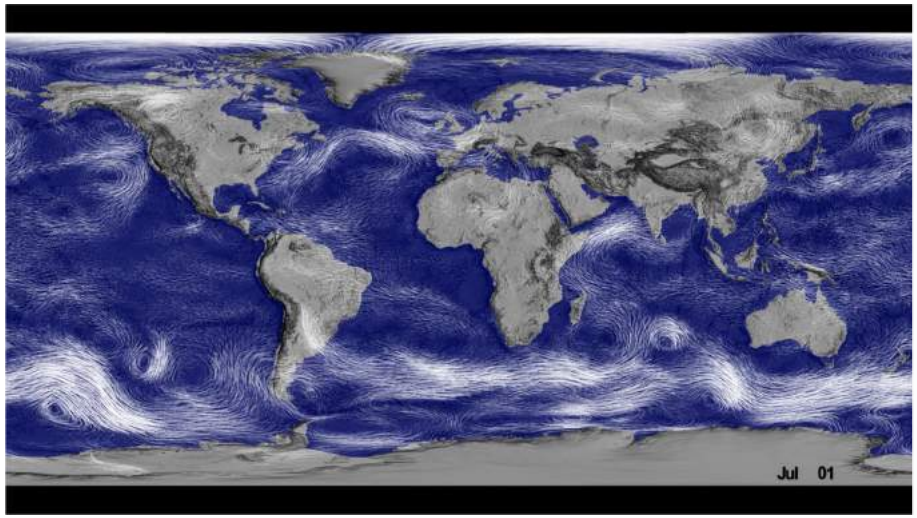


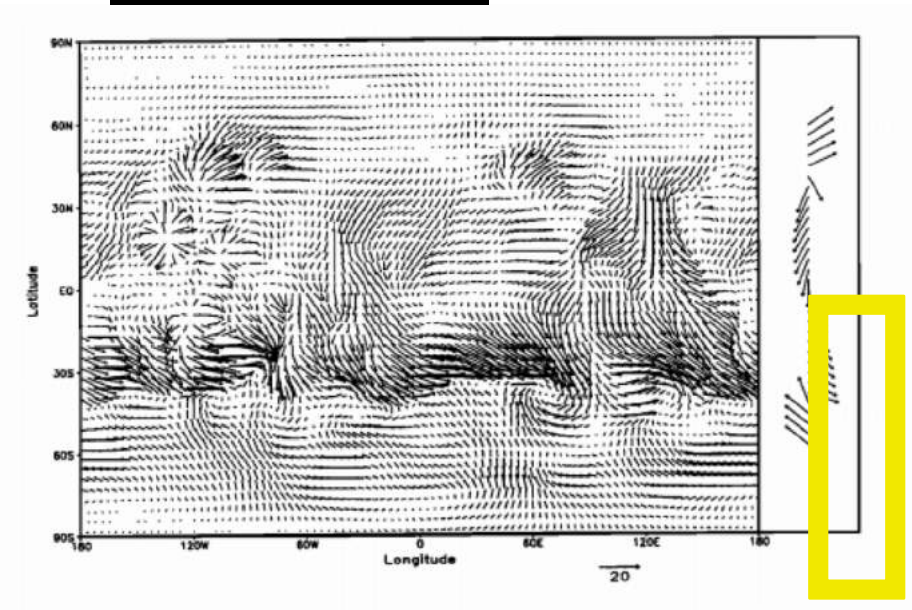
Mars



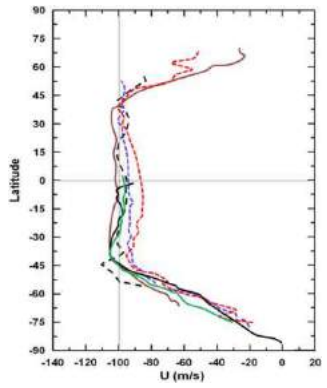
(Lewis et al. 1999)

Surface Winds: Earth and Mars

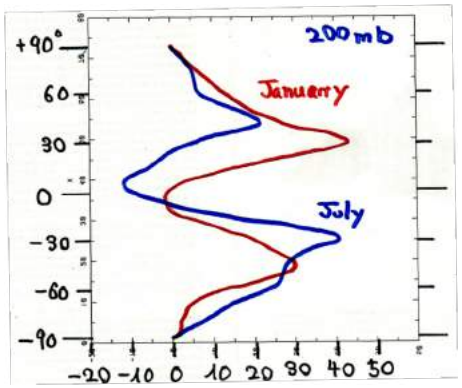




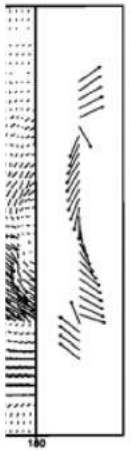
Eastward Winds with Latitudes:



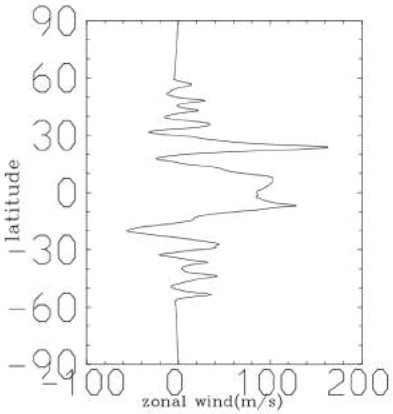
Venus



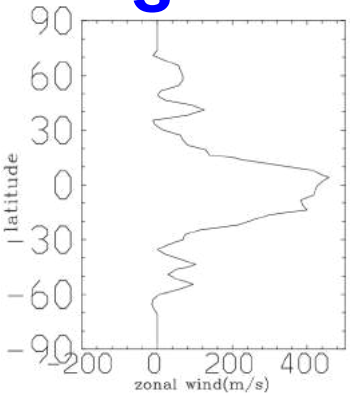
Earth



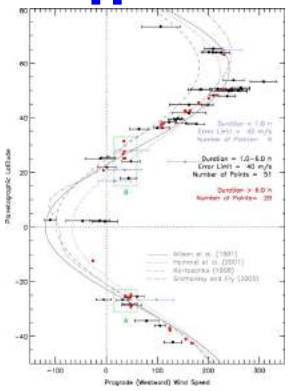
Mars



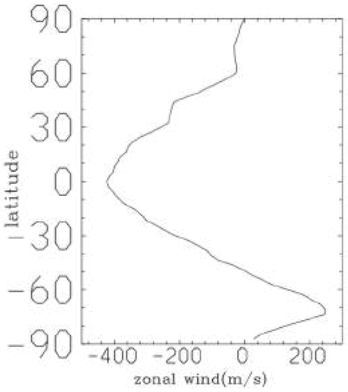
Jupiter



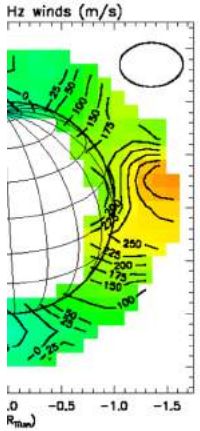
Saturn



Uranus



Neptune



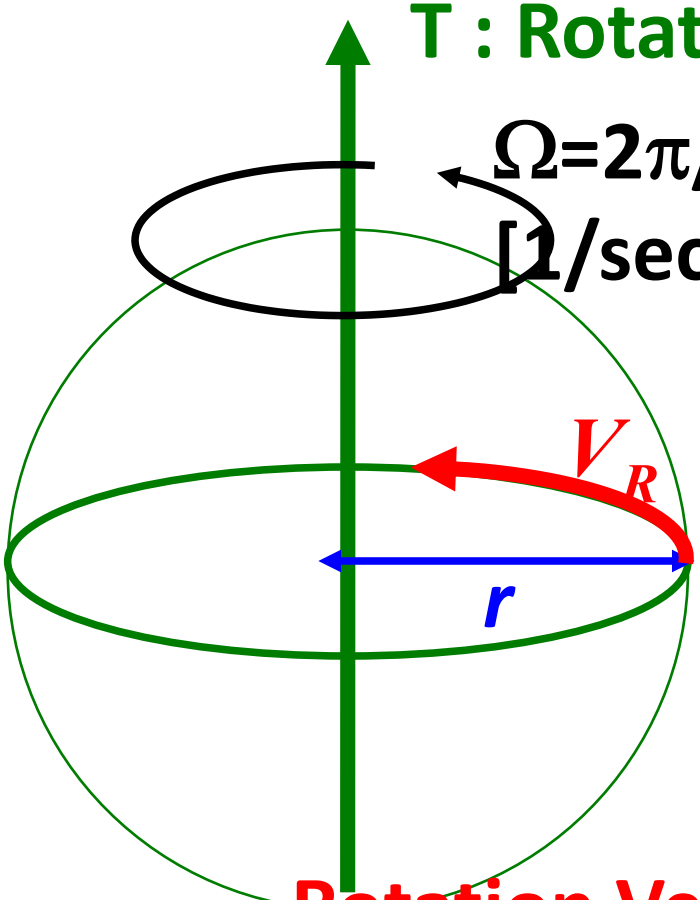
Titan

(Saturn's Satellite)

Basic Characteristics of the Planets:

Planet	Rotation Period	Radius (relative to Earth)	Typical Wind Speed
Venus	-243 days	0.95	100m/s
Earth	24 hours	1.0 (6371 km)	10m/s
Mars	25 hours	0.53	10m/s
Jupiter	10 hours	11	100m/s
Saturn	10 hours	9.4	200m/s
Uranus	18 hours	4.1	100m/s
Neptune	18 hours	3.9	200m/s
Titan	383 hours	0.4	200m/s

Degree of Importance of Rotation?



T : Rotation Period [sec]

$\Omega=2\pi/T$: Rotation Rate [1/sec]

NB: 2π : Circle Length of a Circle with a Unit Radius

***r* : Radius of the Planet [m]**

Rotation Velocity: $V_R = r\Omega = 2\pi r/T$

Typical Wind Velocity: V

T : Rotation Period [sec]

$\Omega=2\pi/T$: Rotation Rate [m/sec]

r : Radius of the Planet [m]

Rotation Velocity: $V_R = r\Omega = 2\pi r/T$

Typical Wind Velocity: V

Degree of Importance of Rotation?:

Typical Wind Velocity/Rotation Velocity= $V/V_R = V/r\Omega$: Rossby Number

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Titan	383 hours	0.4	200m/s

Importance of Rotation?:Rossby number

Planet	Rotation Period	Rossby number
Venus	-243 days	-55
Earth	24 hours	0.02
Mars	25 hours	0.04
Jupiter	10 hours	0.008
Saturn	10 hours	0.02
Uranus	18 hours	0.04
Neptune	18 hours	0.08
Titan	383 hours	17

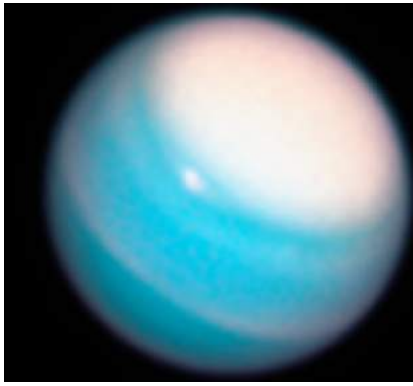
Planets with Atmospheres

In Increasing Order of the Rossby number:

Jupiter

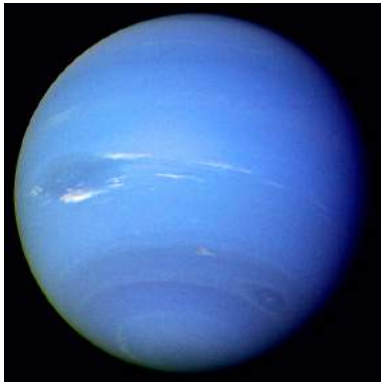
Saturn

Earth



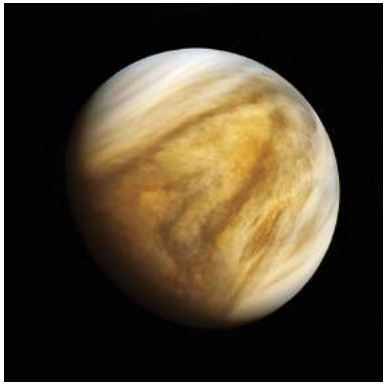
Uranus

Mars



Neptune

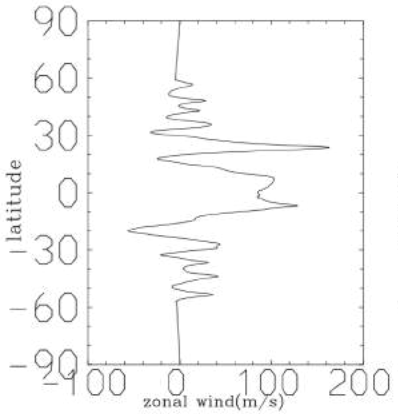
Titan (Saturn's Satellite)



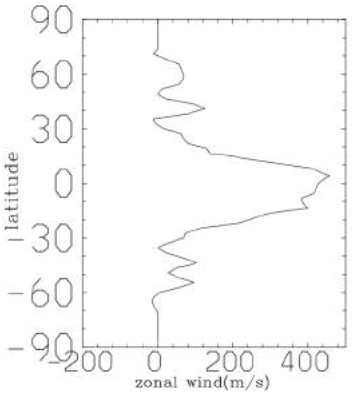
Venus

Eastward Winds with Latitudes:

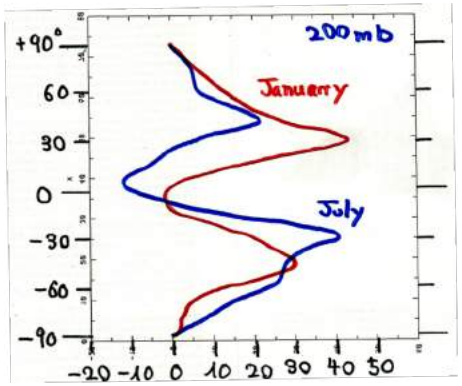
In Increasing Order of the Rossby number:



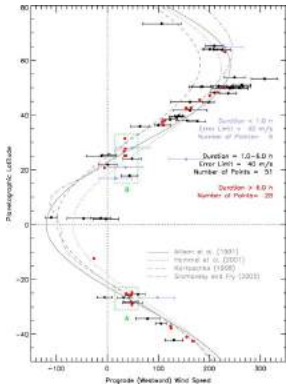
Jupiter



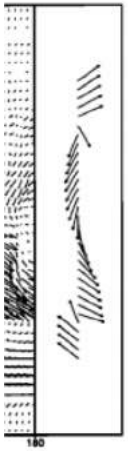
Saturn



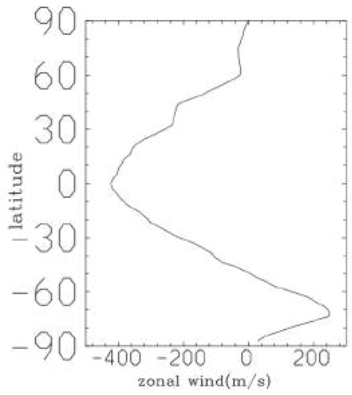
Earth



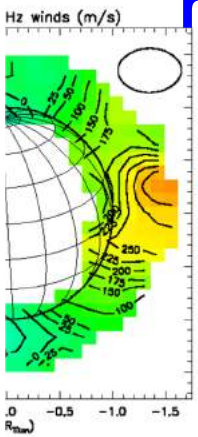
Uranus



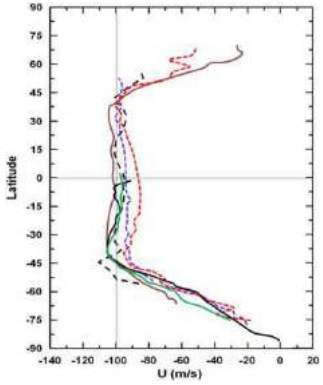
Mars



Neptune



Titan (Saturn's Satellite)



Venus

Conclusions:

Eastward-Wind Profile becomes Finer when the atmosphere is More strongly controlled by Rotation

Eastward-Wind Profile becomes Broader when the atmosphere is Less strongly controlled by Rotation

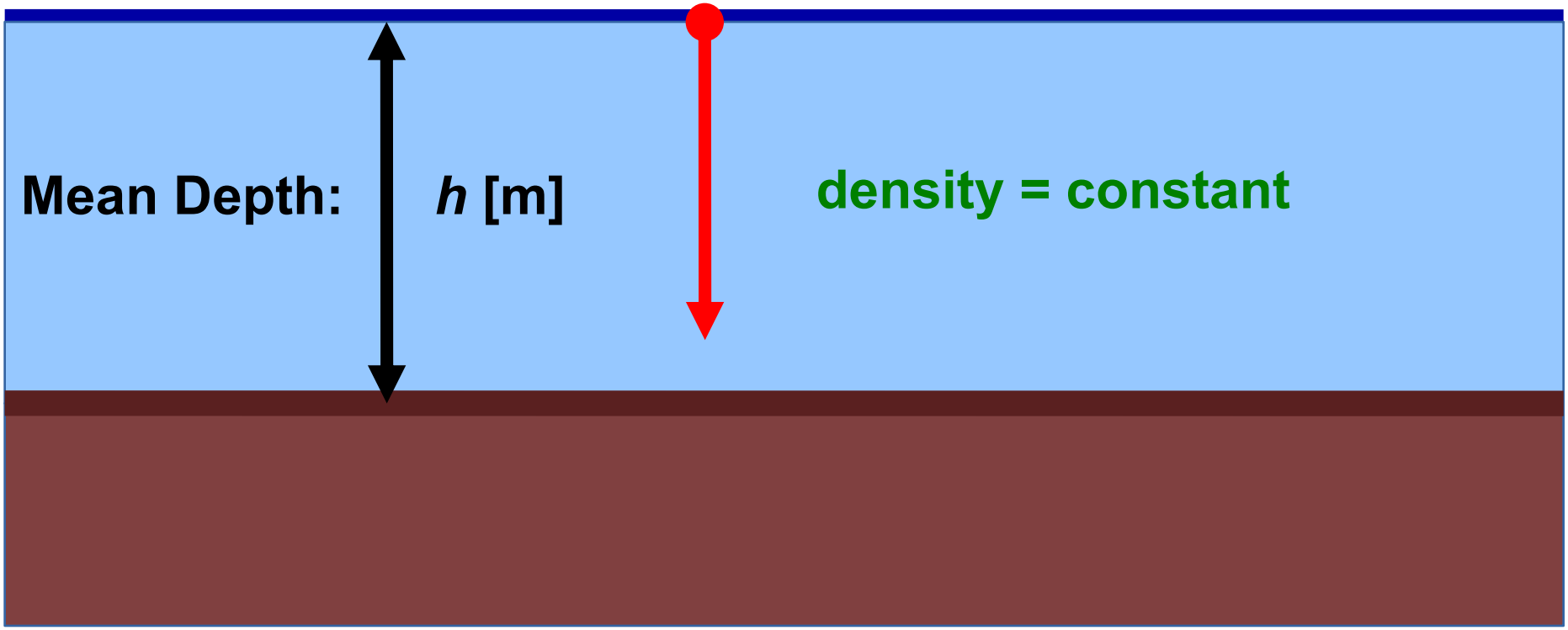
But Why?

Idealized Atmosphere

[Forget Rotation For Now]

g, Gravity
[m/s^2]

no mass (vacuum)

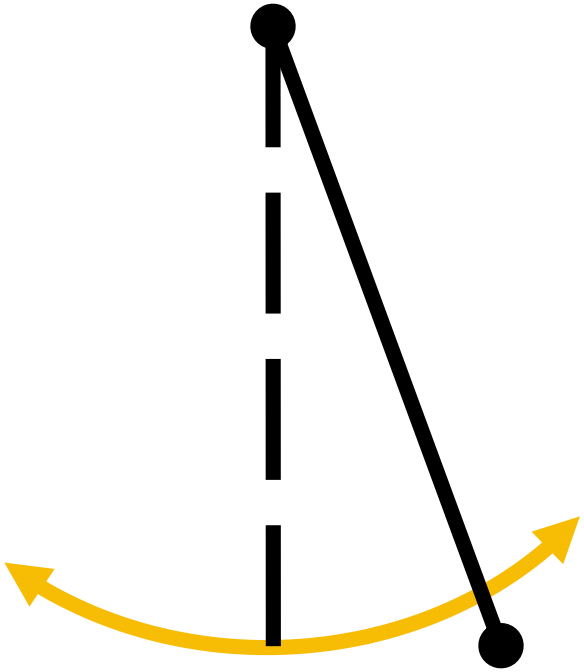


Idealized Atmosphere

[Forget Rotation For Now]

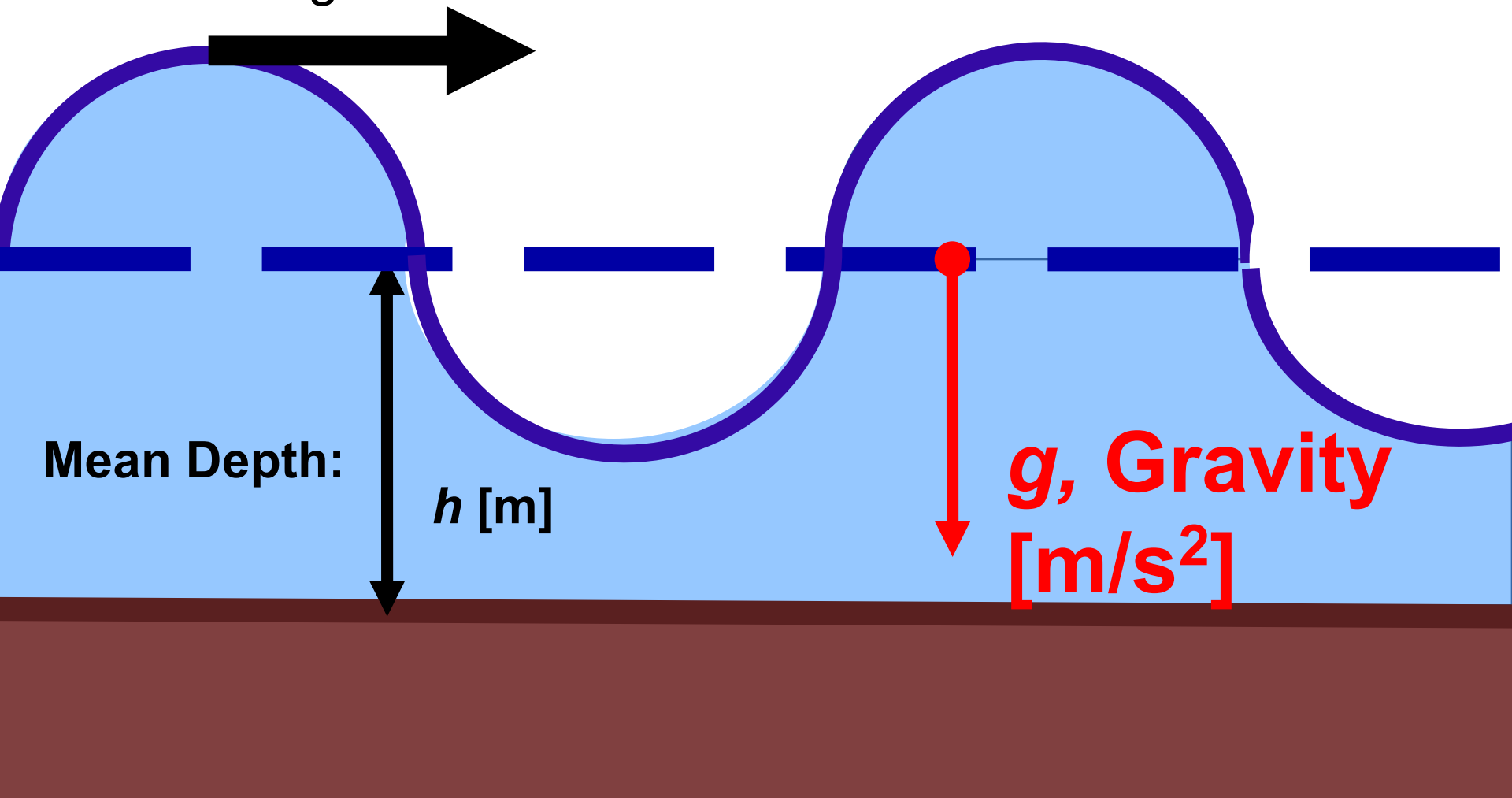
Basic Driving Force?: Gravity, *g*

cf., Pendulum:



Mode of Movements: Gravity Wave (cf., Pendulum)

$c_g=(gh)^{1/2}$: Gravity-Wave Speed



Two Basic Modes of Movements:

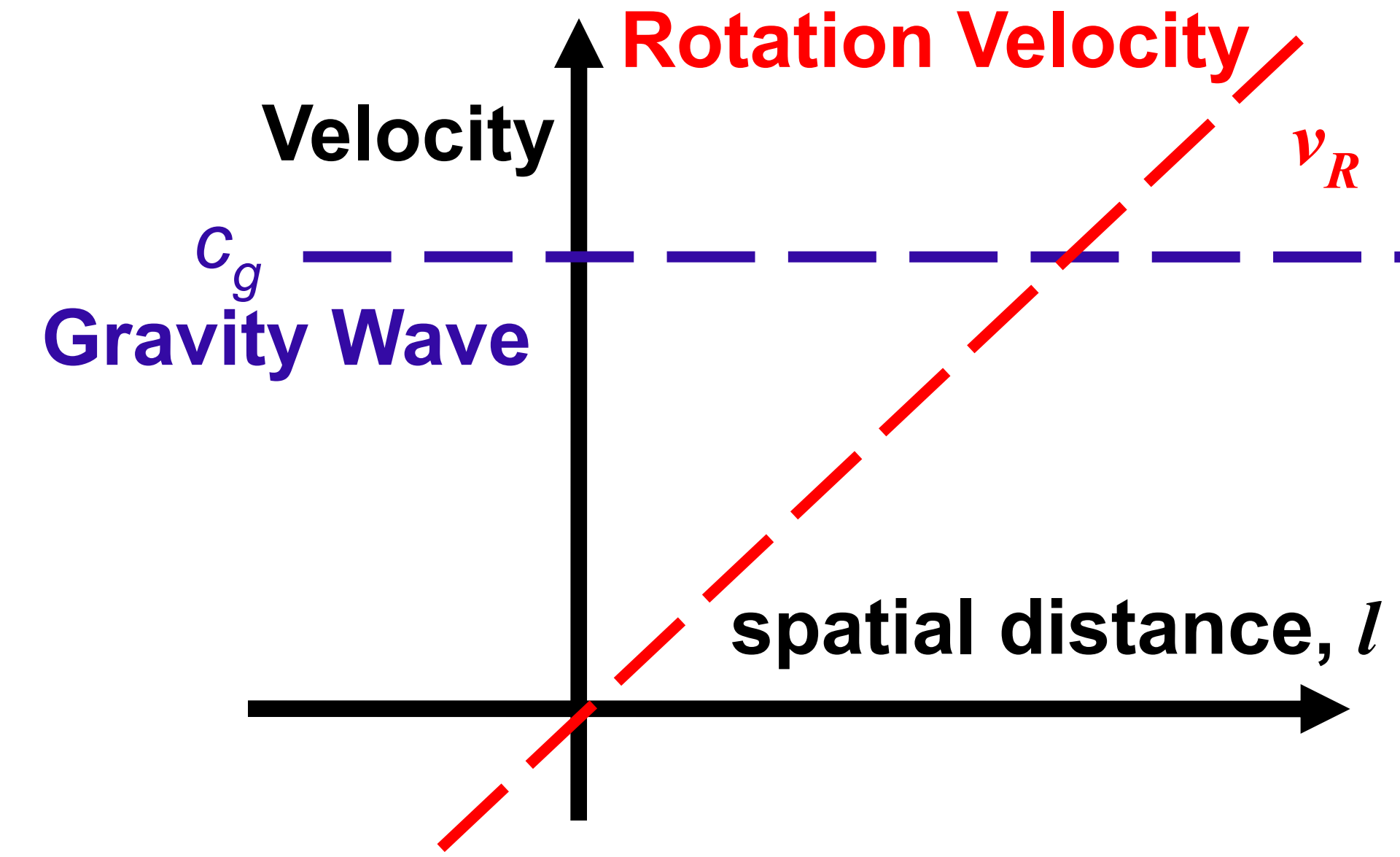
Gravity-Wave Speed: $c_g=(gh)^{1/2}$

Rotation Velocity : $v_R = l\,\Omega$

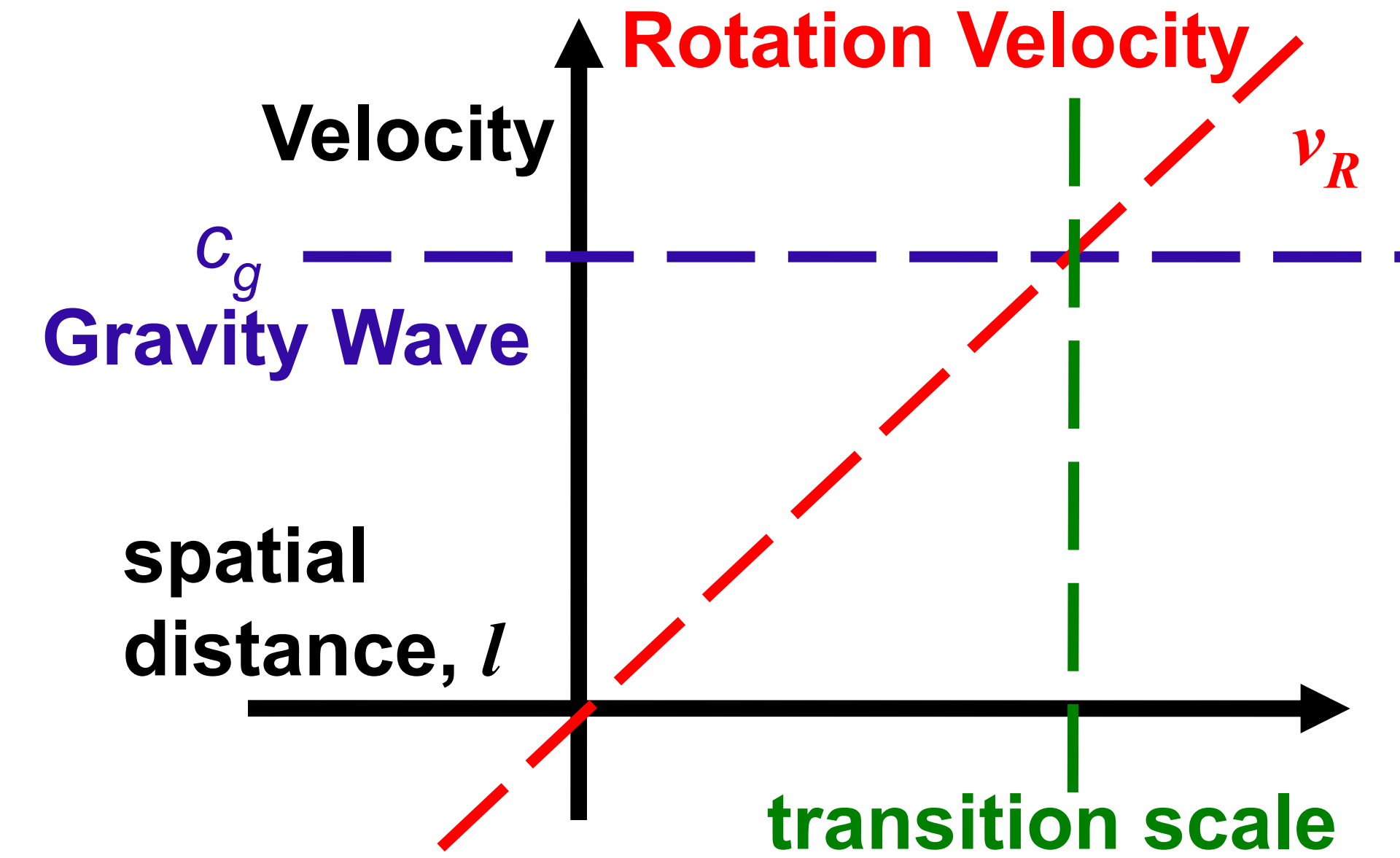
(generalized) for a spatial distance, l

(length of arm)

Two Basic Modes of Movements:



Two Basic Modes of Movements:



Transition Scale:

Gravity Wave = Rotation Velocity

$$c_g = v_R$$

$$c_g = l\,\Omega$$

transition scale: $l = \Omega / c_g$ **:**

typical scale of the weather

relative transition scale (to radius):

$$l/r = \Omega / r c_g$$

Problem with estimating the Transition Scale:

$h = ?$ or $c_g = ?$

NB: *h* is only an *effective* depth of the atmosphere

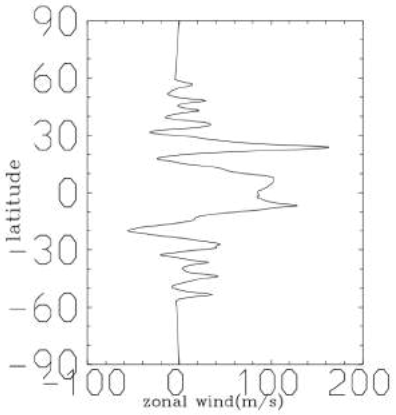
Set : $c_g = 50$m/s: typical value in the Earth's atmosphere

Nondimensional Parameters:

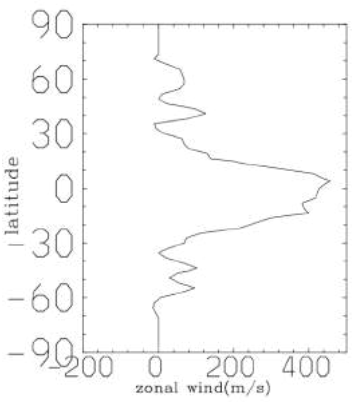
Planet	Rossby number	Transition Scale (relative to the radius)
Venus	-55	-27
Earth	0.02	0.1
Mars	0.04	0.2
Jupiter	0.008	0.0041
Saturn	0.02	0.0048
Uranus	0.04	0.020
Neptune	0.08	0.021
Titan	17	4.3

Eastward Winds with Latitudes:

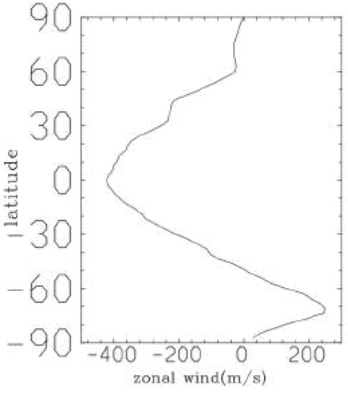
In Increasing Order of the Transition Scale:



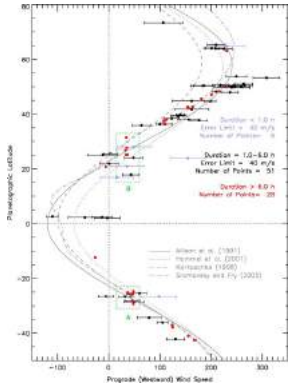
Jupiter



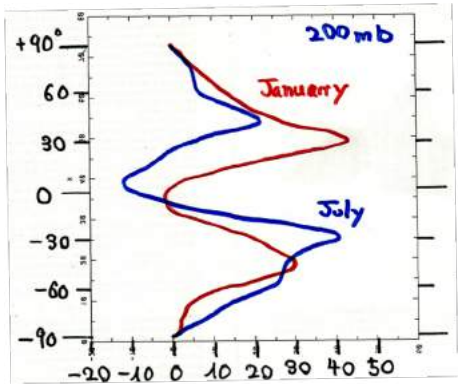
Saturn



Neptune

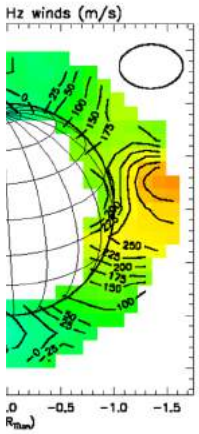


Uranus

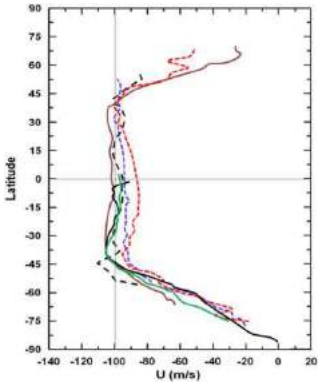


Earth

Mars



Titan
(Saturn's Satellite)



Venus

Conclusions (1):

Weather of the atmosphere is characterized by the scale in which the gravity-wave speed, $c_g = (gh)^{1/2}$, becomes equal to the rotational velocity, $V_R = l\Omega$.

i.e.,

Transition Scale: $l = \Omega / c_g$

Conclusions (2):

As a result, as the planet rotates faster (slower), the scale that characterizes the weather becomes smaller (larger)

Conclusions (3):

With slower rotations:
weather is smoother with less dependence in longitude (e.g., Hadley cell)

With a very slow rotation: the winds blow very fast eastwards (in the direction of rotation)

Conclusions (4):

With faster rotations:

- the weather realizes in smaller scales and evolves faster
- number of jet streams (eastward-wind peaks) increases
- more features are found in the longitudinal direction

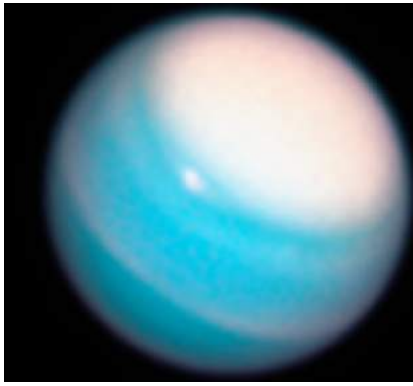
Planets with Atmospheres

In Increasing Order of the Rossby number:

Jupiter

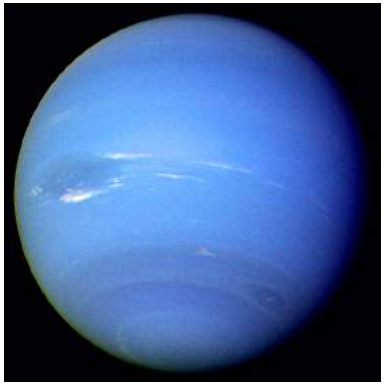
Saturn

Earth



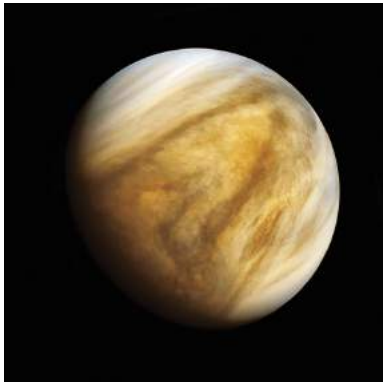
Uranus

Mars



Neptune

Titan (Saturn's Satellite)



Venus

Wisdom of This Talk:

"Simplify, Simplify Simplify"

(Henry David Thoreau, *Walden*)