The Abdus Salam
International Centre
for Theoretical Physics

Postgraduate Diploma Programme

Earth System Physics

Wave physics

Introduction

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System

- A **system** is a set of interacting or interdependent component parts forming a complex/intricate whole
  - Every system is delineated by its spatial and temporal boundaries, surrounded and influenced by its environment, described by its structure and purpose and expressed in its functioning
- In engineering and physics, a physical system is the portion of the universe that is being studied (of which a thermodynamic system is one major example)
- An **open** system exchanges matter and energy with its surroundings. A **closed** system exchanges energy, but not matter, with its environment; like Earth. An **isolated** system exchanges neither matter nor energy with its environment

http://www.merriam-webster.com/dictionary/system
Citation: Pidwirny, M. (2006). "Definitions of Systems and Models".
http://www.physicalgeography.net/fundamentals/4b.html

What is a System?

- **Systems**
  - a group of interacting parts that work to together to do a job or to form a whole
    - Open Systems
    - Closed Systems

What is a System?

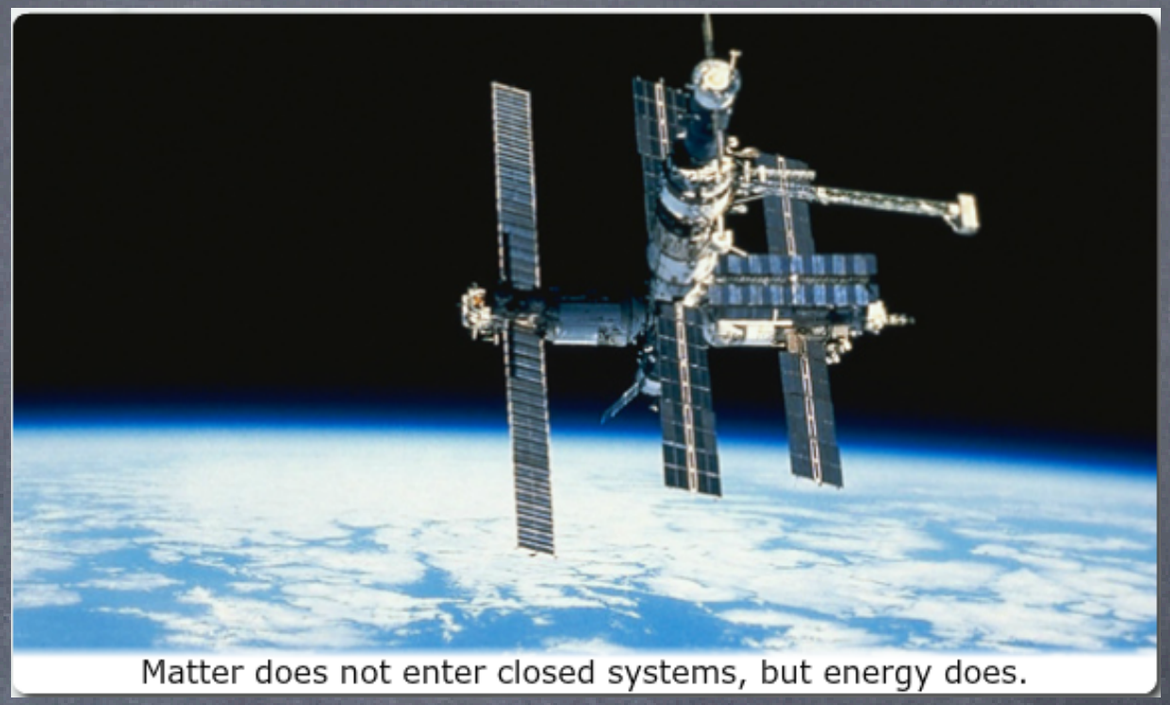
- Systems
  - Open System
    - Matter and energy can flow into and out of the system
      - Uncovered pan of boiling water
      - Vegetable Garden
      - Natural Environment

A car is an open **system**. Matter and energy move in.

Matter and energy move out of an open system.

What is a System?

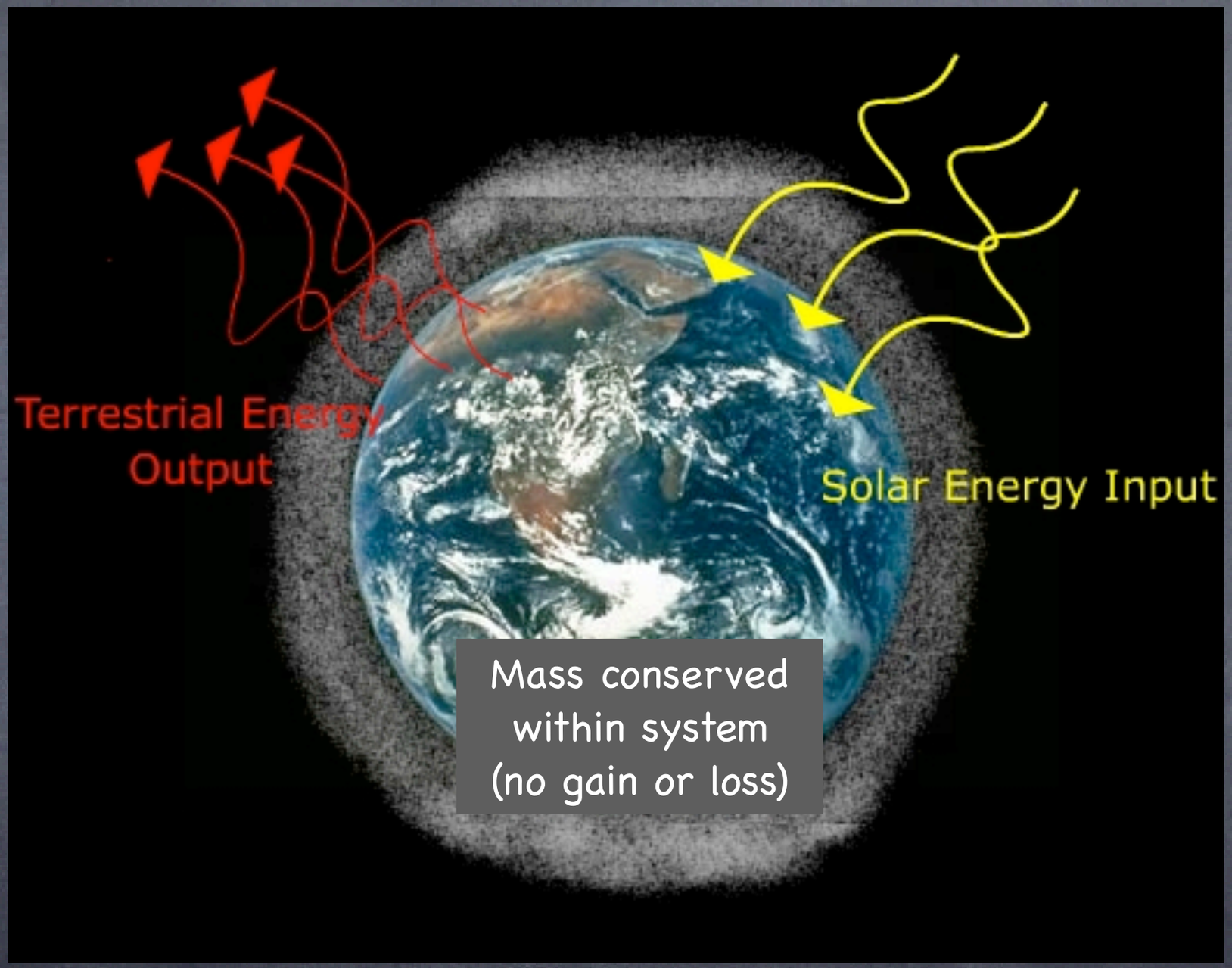
- Systems
  - Closed System
    - Matter cannot enter or leave, energy can
      - Covered pan of boiling water
    - Terrarium
    - Greenhouse



Matter does not enter closed systems, but energy does.

Matter moves around inside closed systems. Energy moves out.

Earth as a closed System



Closed system: exchange of energy but negligible exchange of mass with surroundings

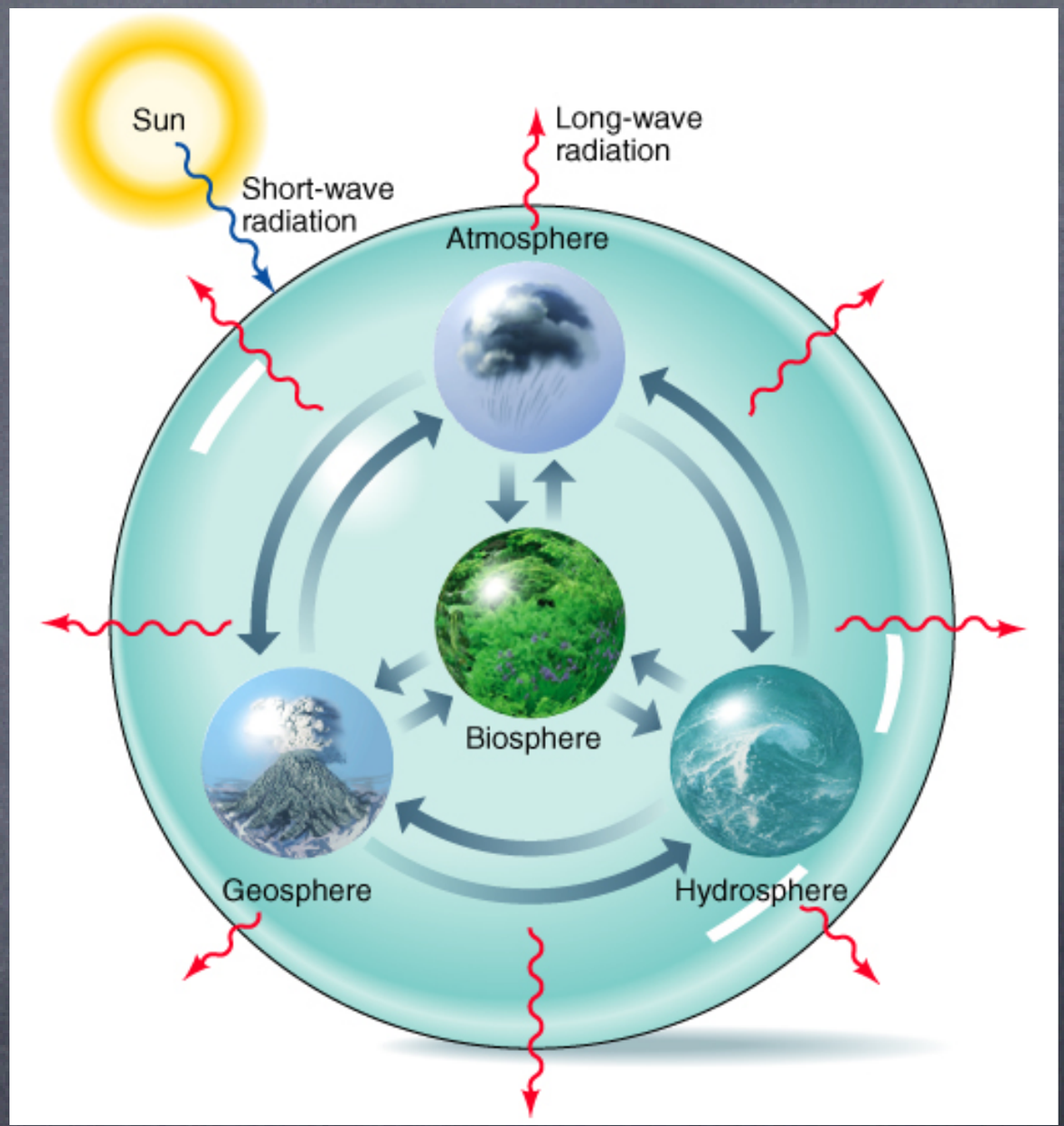
Earth System Physics

- Study the processes and interactions (cycles) among the **atmosphere**, **hydrosphere**, cryosphere, biosphere, and **geosphere** from a global to local point-of-view, and across the time scales (minutes to eons) in which these spheres interact.
- It requires the use of **physical** and chemical laws with mathematics to describe the physical, chemical and biological processes within each sphere and the interactions between the spheres.
- These descriptions are used along with observations to construct **models** through which complex interactions of the spheres are studied.
- It is through the understanding of these complex interactions that accurate, **predictive** models are developed.

Earth System

Earth System

- A **complex** system made up of:
  - **Matter**
    - Living Things
    - Nonliving things.
  - **Energy**
  - **Processes** within Earth's
    - Matter and energy continuously cycled through the smaller systems that make up Earth's spheres.



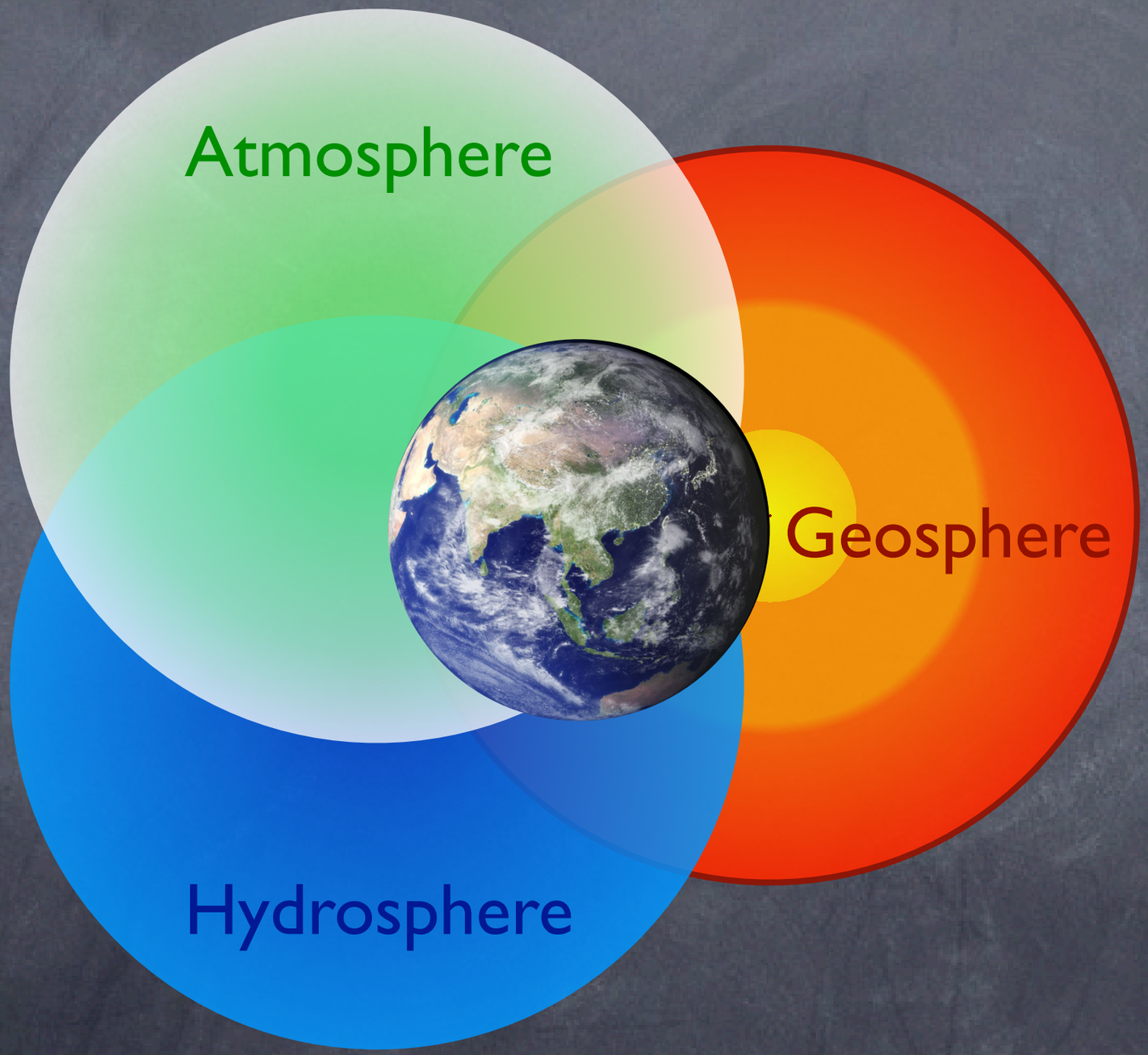
Major Themes

Scale Processes in the Earth system act on length scales of microns to thousands of kilometers, and on time scales of milliseconds to millions of years.

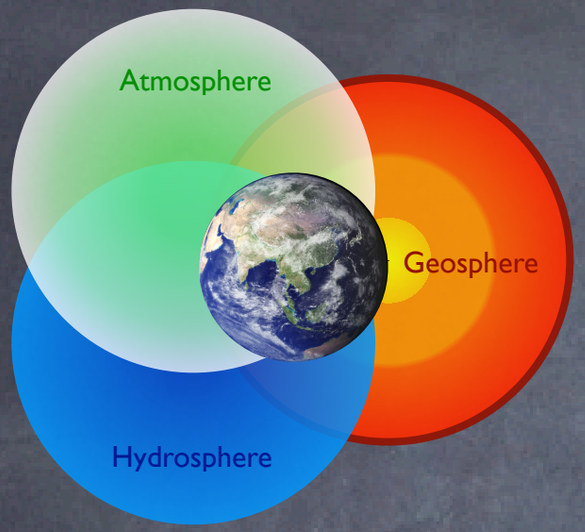
Energy The Earth system is powered by one external source (the Sun) and two internal ones: radioactive decay, and gravitational energy (heat still being lost from planetary formation).

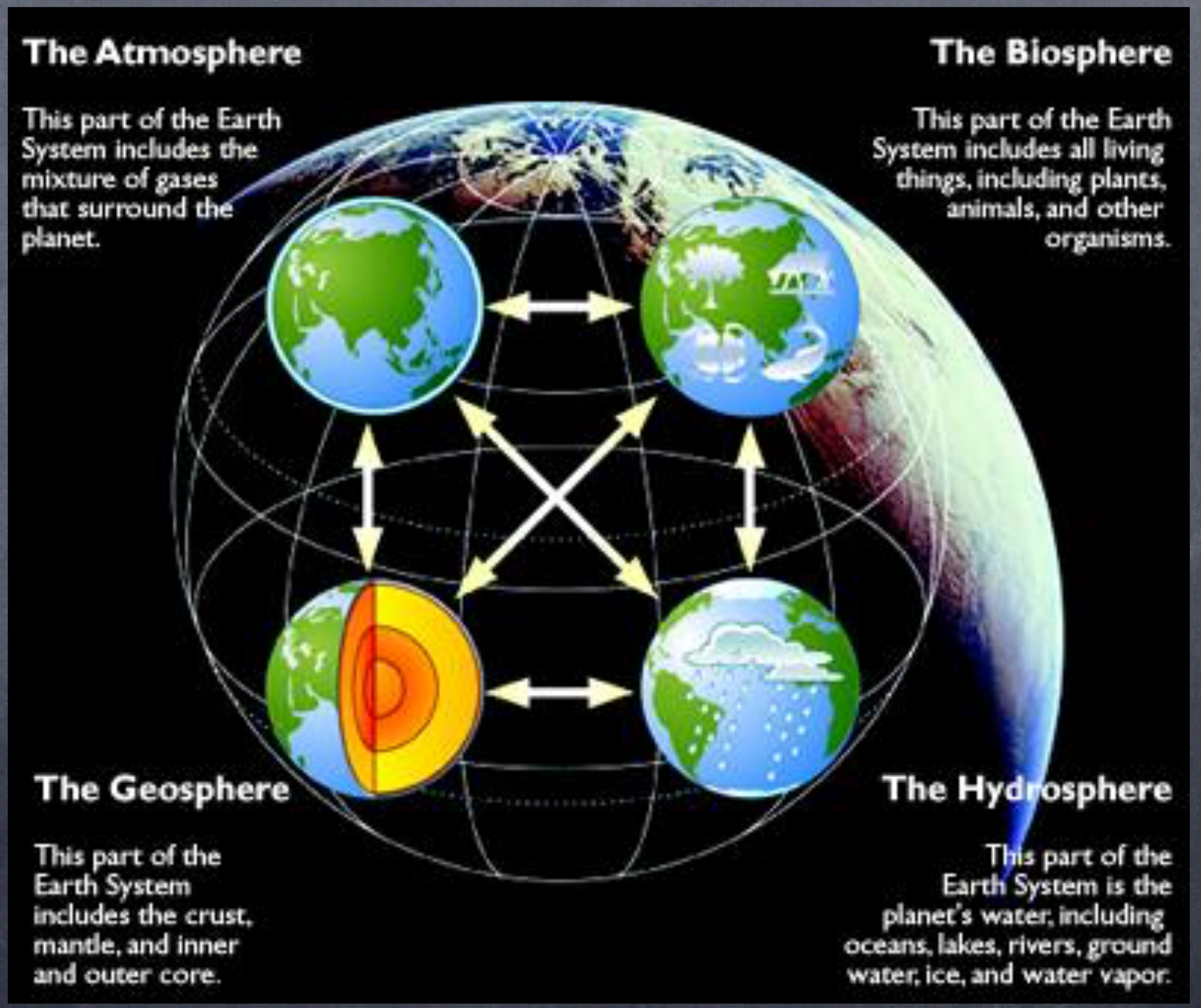
Cycles Material in the Earth system is continually recycled in numerous overlapping cycles.

Earth system



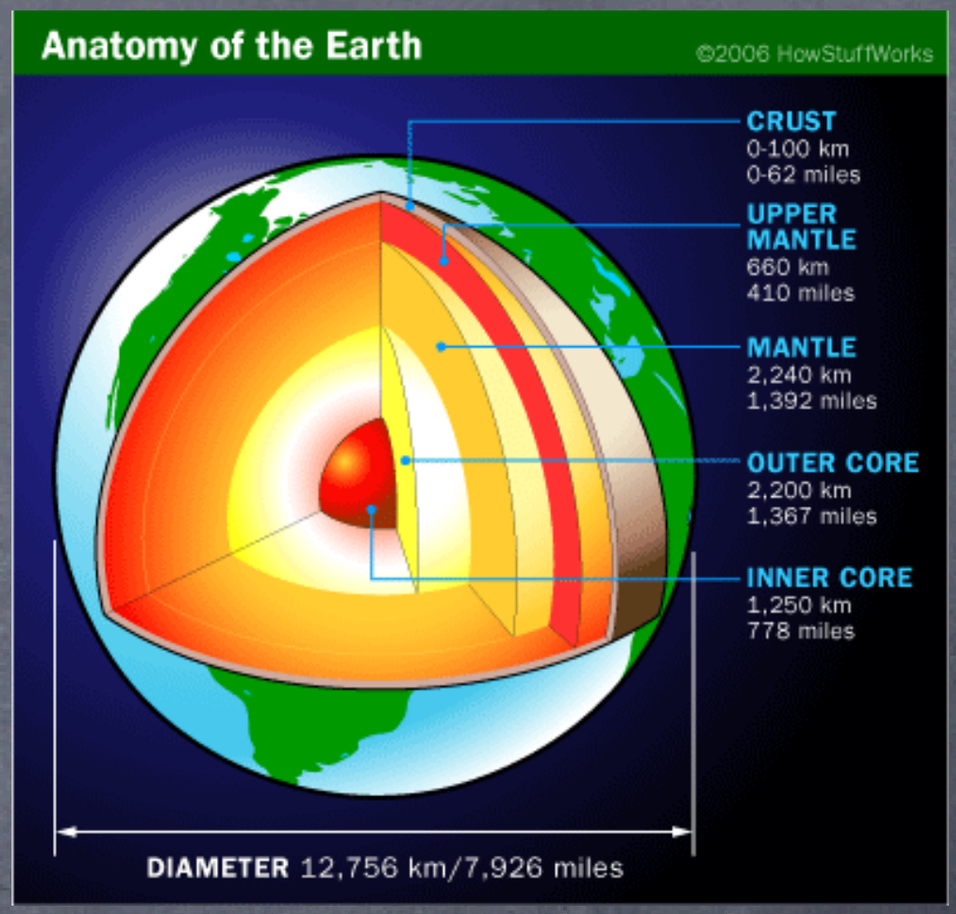
Earth system



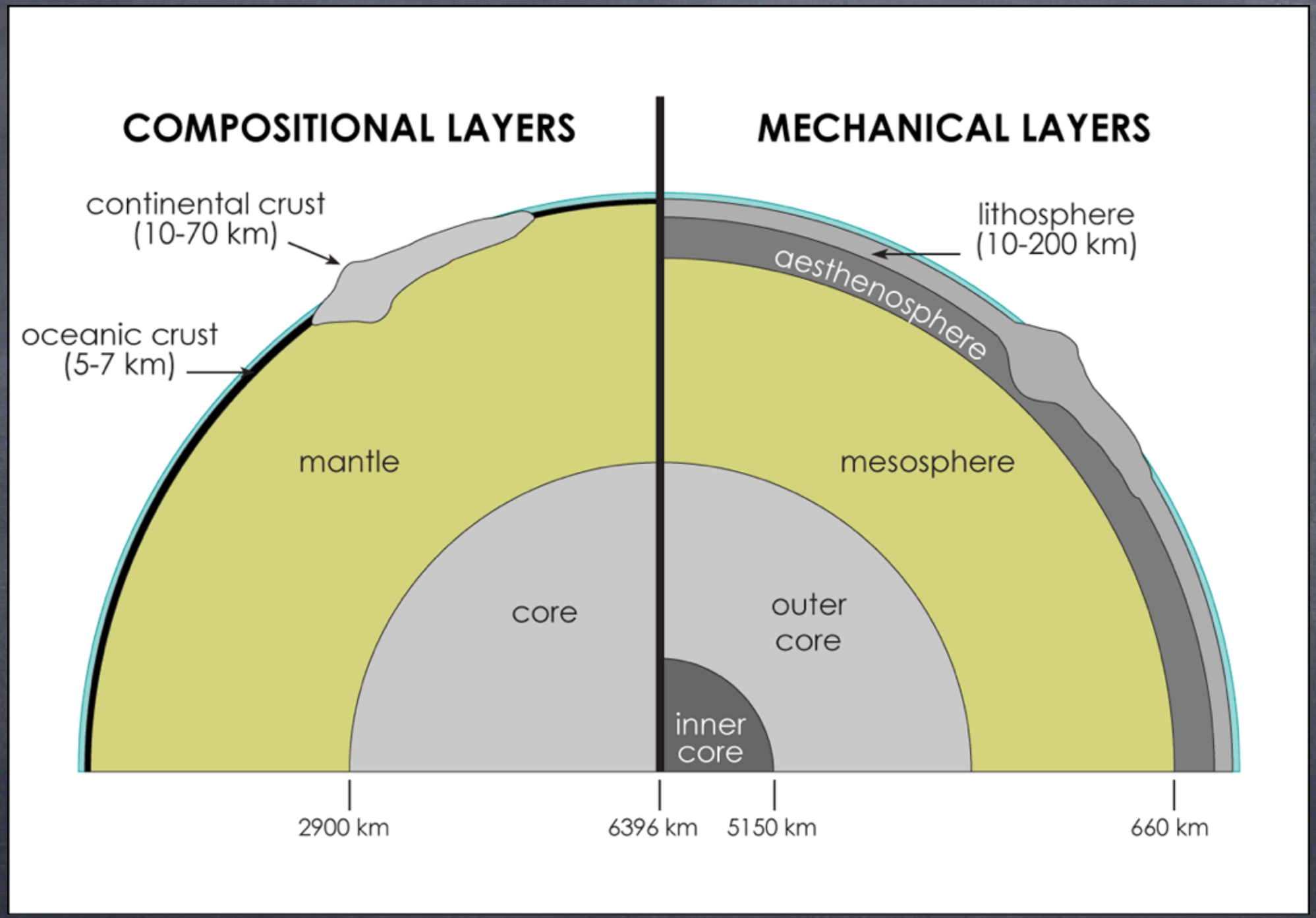


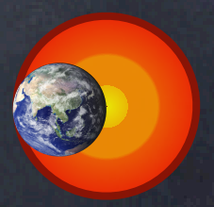
What is the Earth's Geosphere?

- **Geosphere**
  - Mostly solid, rocky part of the Earth.
  - Divided into 3 Layers
    - 1. Crust
    - 2. Mantle
    - 3. Core
      - a. Inner Core
      - b. Outer Core



Earth system: geosphere





Earth layers

Composition

Primarily silica plus light metallic elements →

crust

mantle

Primarily silica plus iron and magnesium →

core

Primarily iron and nickel →

Mechanical Characteristics

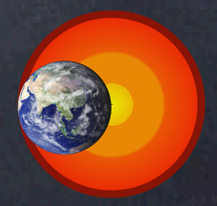
lithosphere ← brittle solid

asthenosphere ← solid (but nearly liquid)

mesosphere ← solid

outer core ← liquid

inner core ← solid



V_P V_S
ρ P
K μ

Seismic tomography

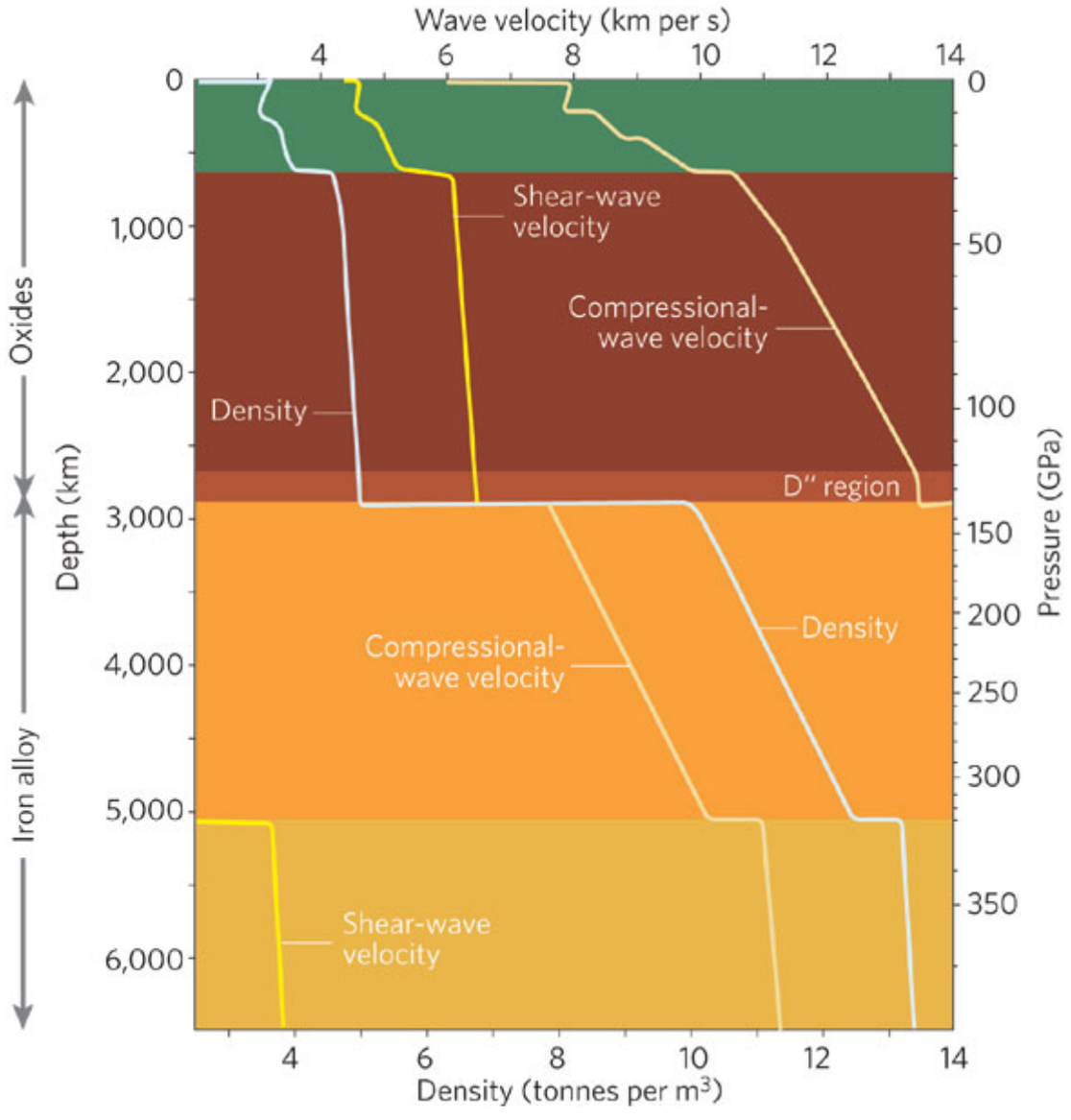
Mean density

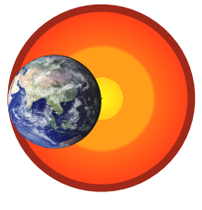
Moment of inertia

Equation of state
A-W equation
Birch's law

Seismological model

Bullen parameter





Compositional model

Mineralogy
Assemblage
Chemistry

Bulk composition

(T,P) phase diagrams

Seismic tomography

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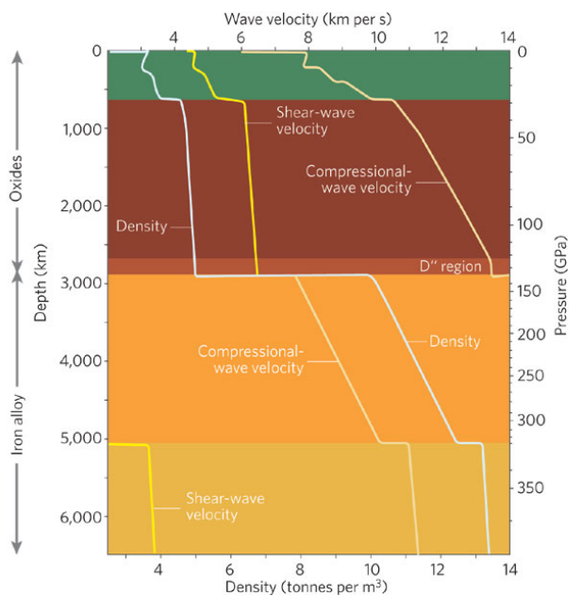

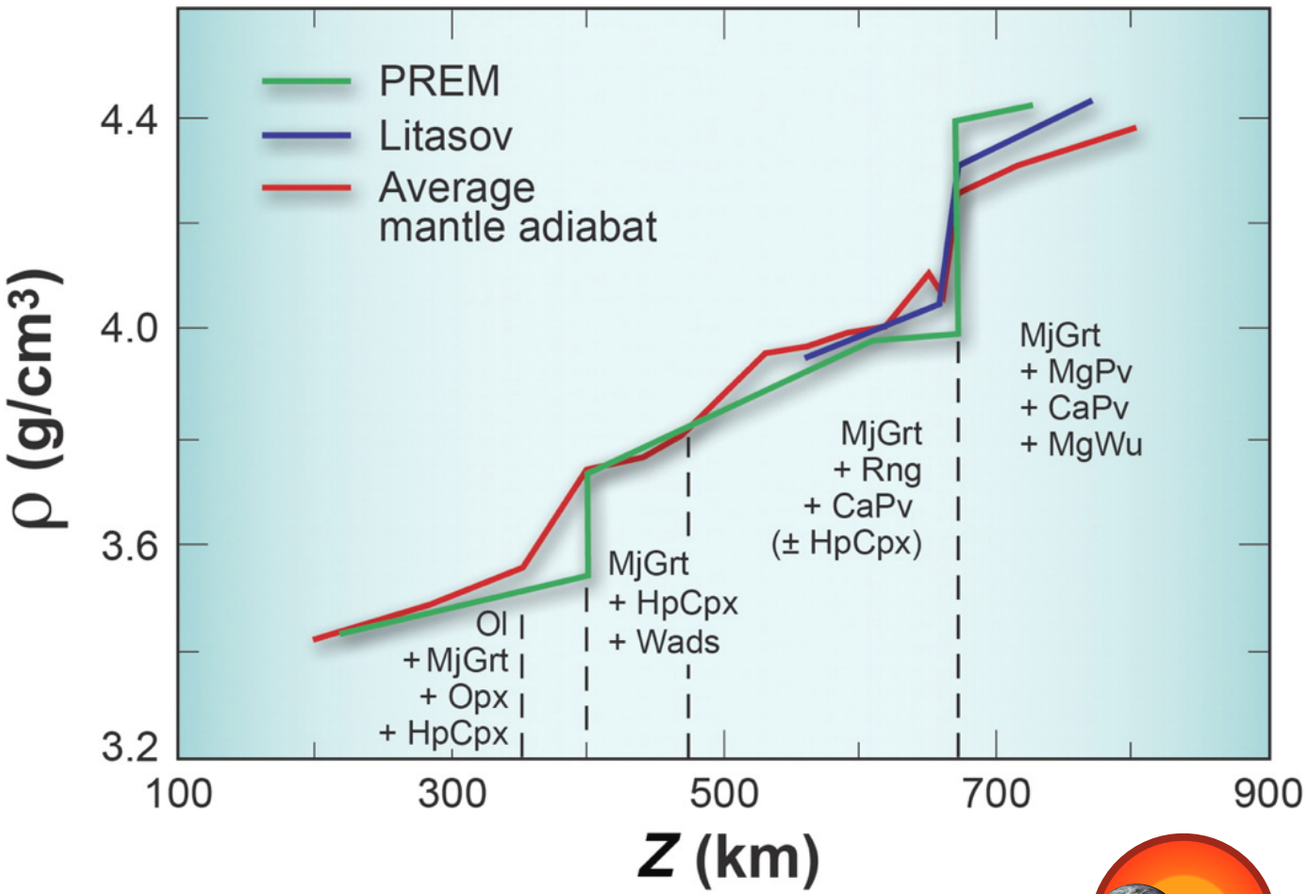

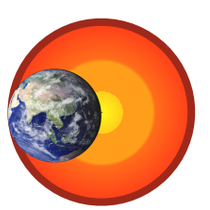

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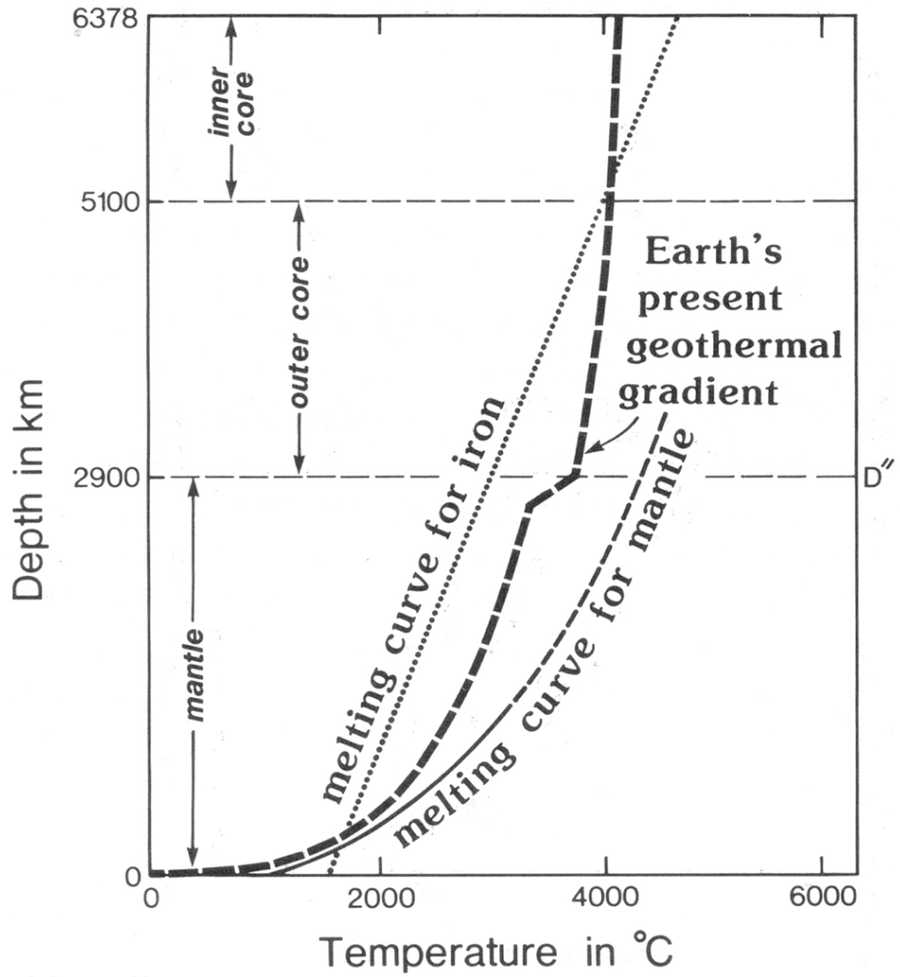
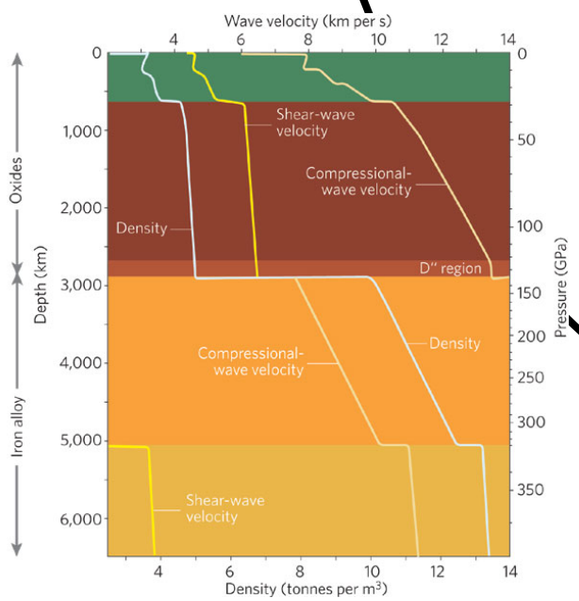




Bullen parameter

Heat flux

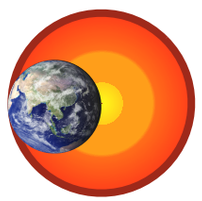
Anchoring points

Adiabatic gradient

Mantle viscosity

Thermal model

T



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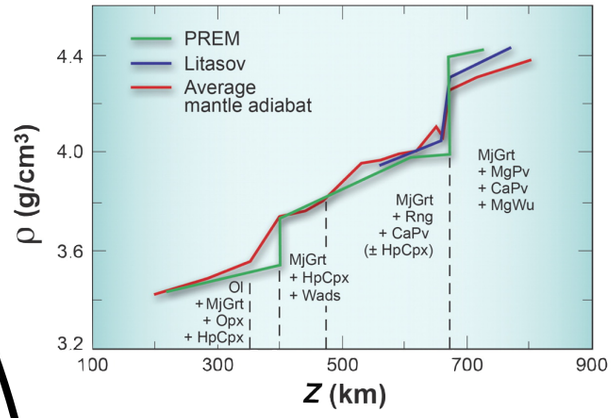
Chemistry



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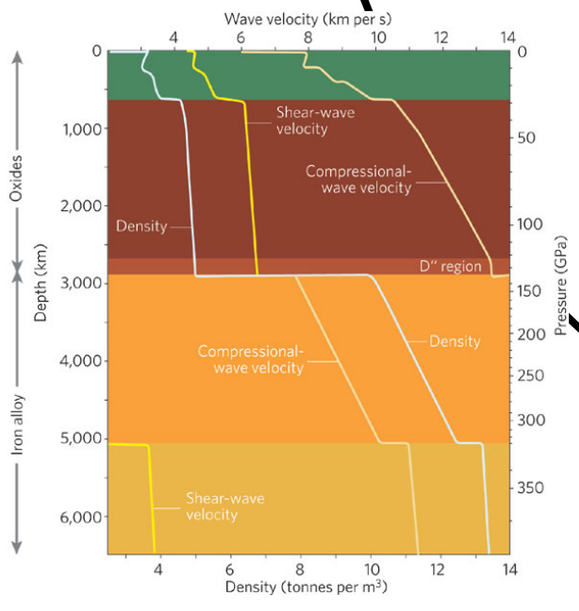

Thermal model

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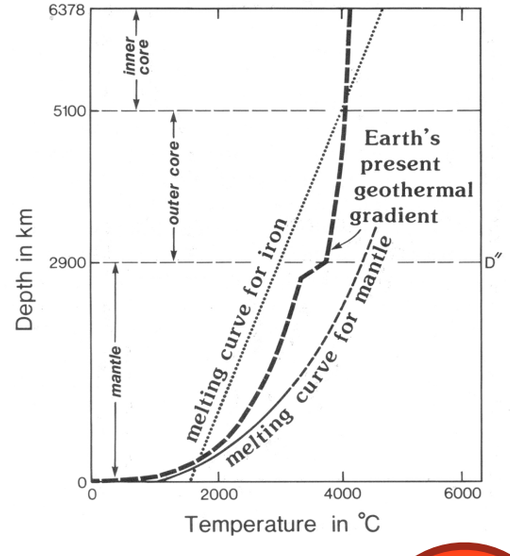
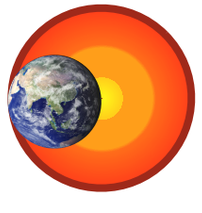
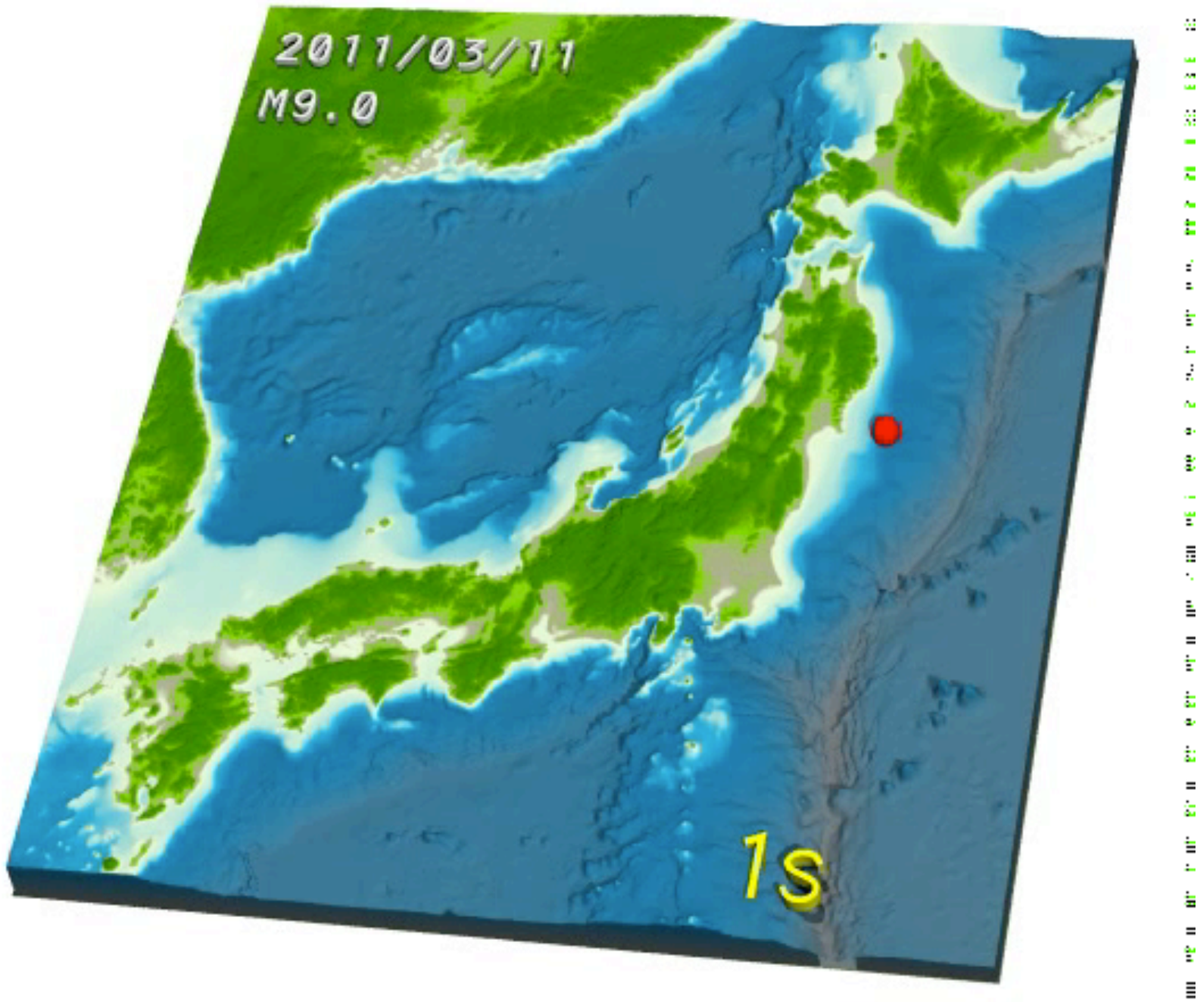




Ground motion animation: time scales...



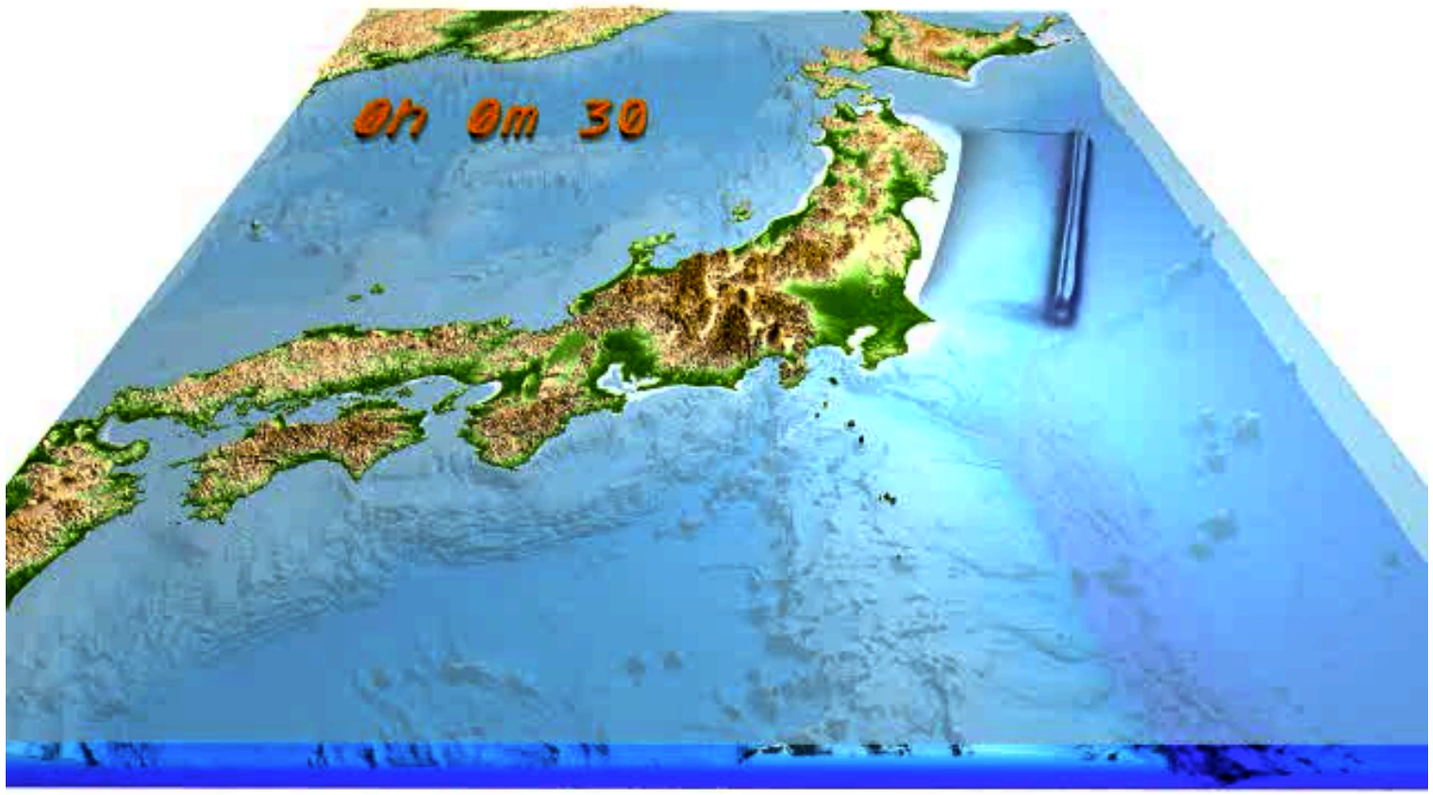
Courtesy of Takashi Furumura

Tsunami animation: time scales...

http://outreach.eri.u-tokyo.ac.jp/eqvolc/201103_tohoku/eng/

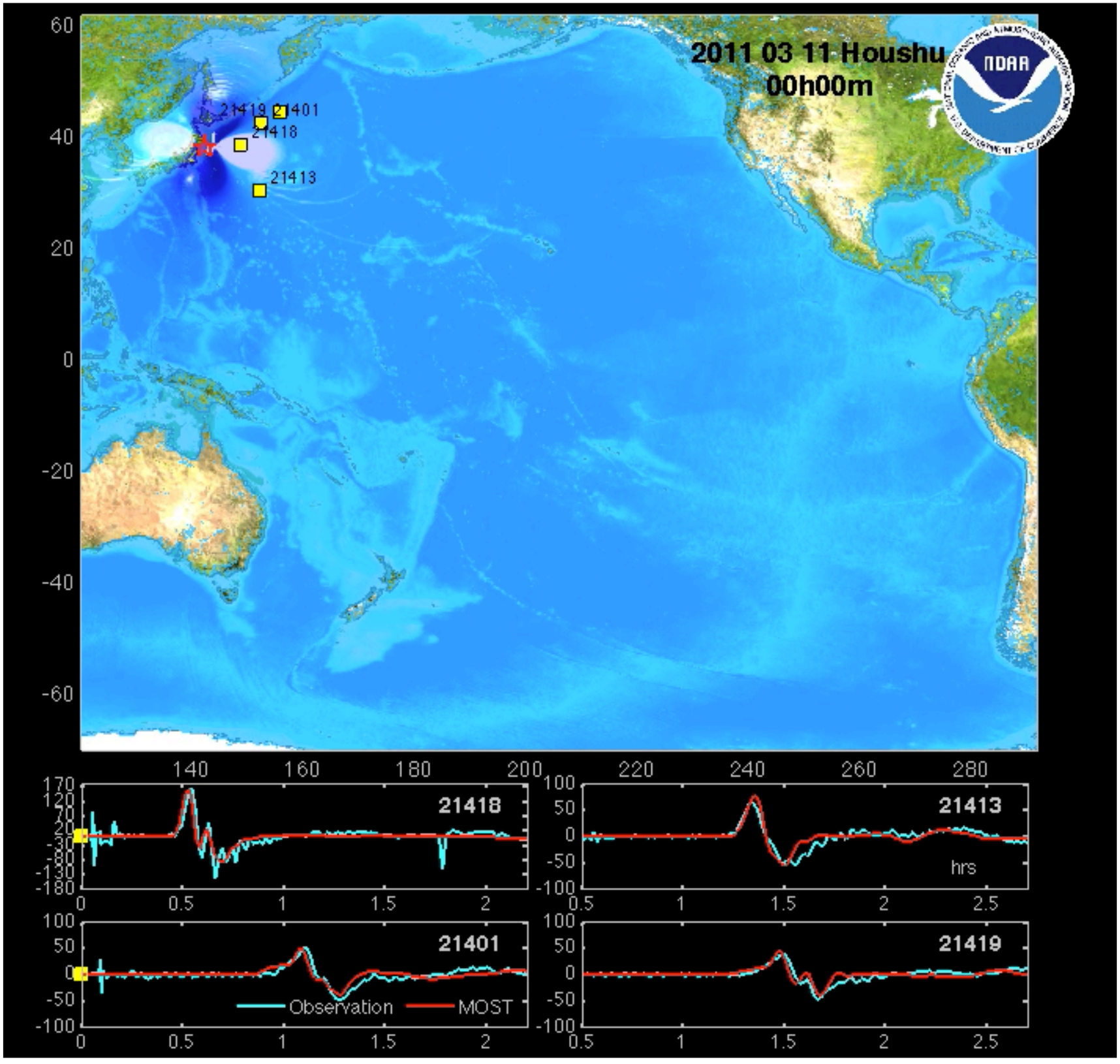
http://supersites.earthobservations.org/honshu.php

http://eqseis.geosc.psu.edu/~cammon/Japan2011EQ/



"Earthquake Research Institute, University of Tokyo, Prof. Takashi Furumura and Project Researcher Takuto Maeda"

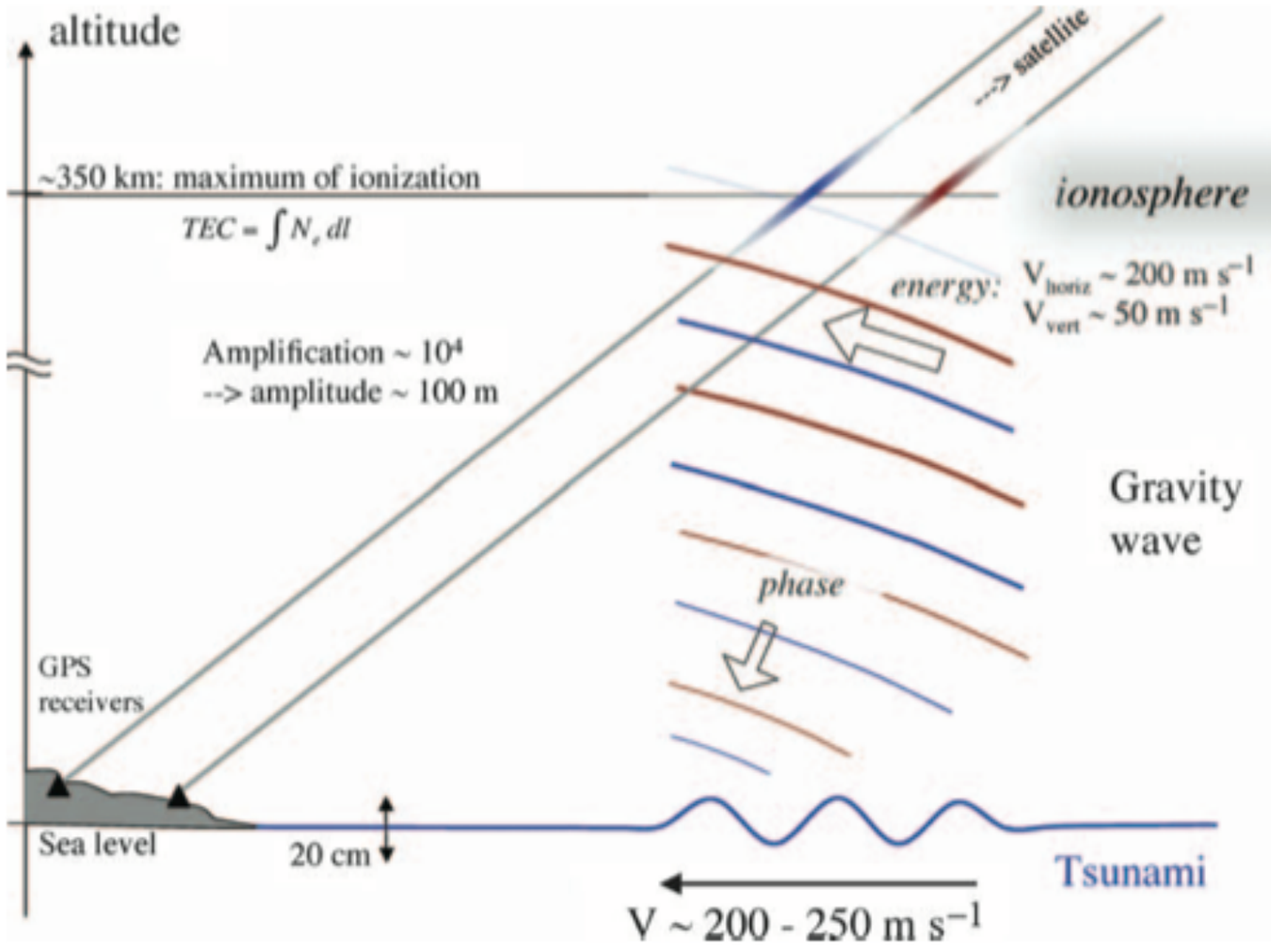
Tsunami animation - NOAA



Tsunami signature in the ionosphere

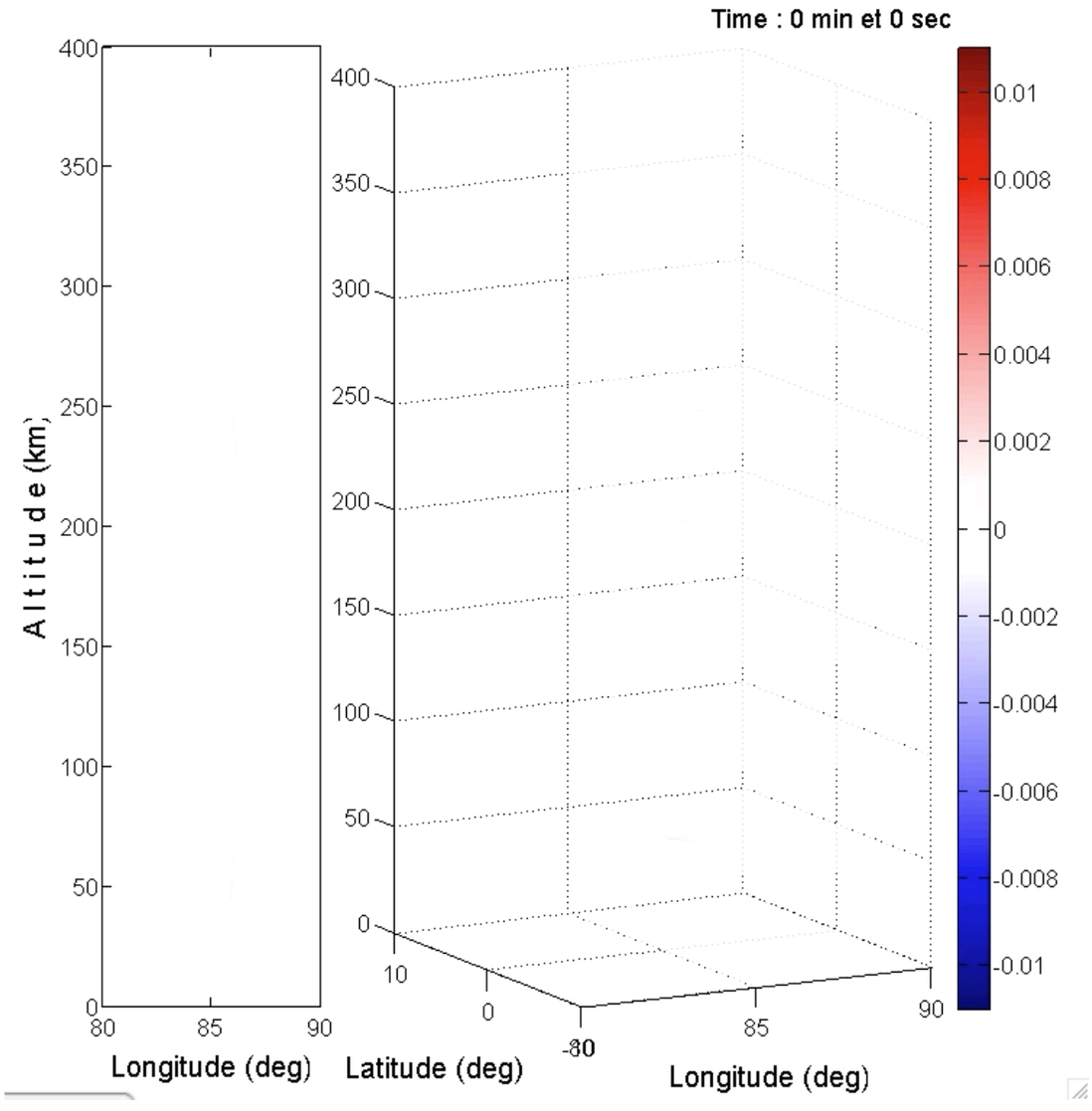
By dynamic coupling with the atmosphere, acoustic-gravity waves are generated

Traveling Ionospheric Disturbances (TID) can be detected and monitored by high-density GPS networks

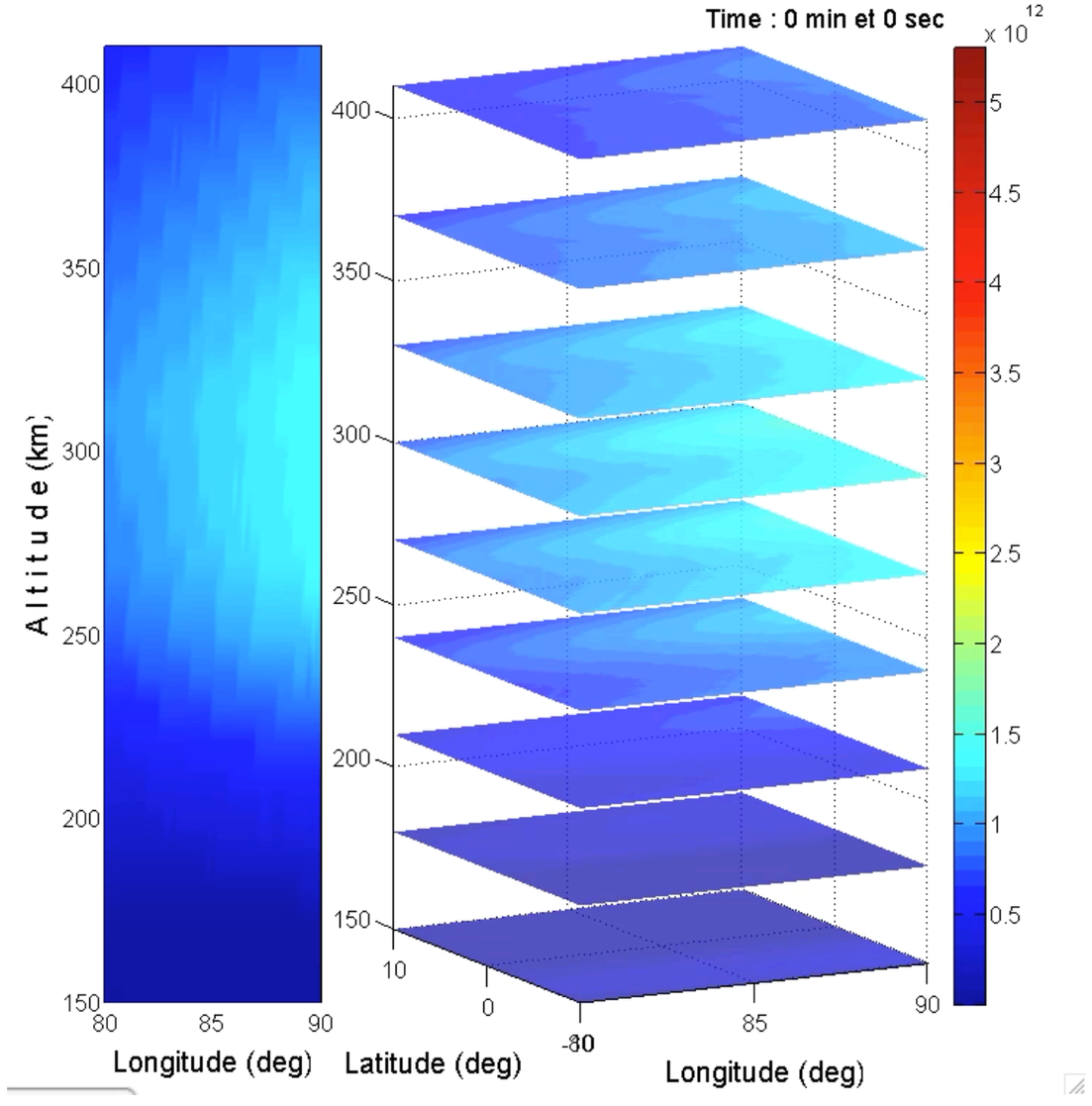


Tsunami signature in the ionosphere

Tsunami-generated IGWs and the response of the ionosphere to neutral motion at 2:40 UT.



Normalized vertical velocity



Perturbation in the ionospheric plasma

Tsunami signature in the ionosphere

- The TEC (Total Electron Content) perturbation induced by tsunami-coupled IGW is superimposed on a broad local-time (sunrise) TEC structure.