Geophysical Fluid Dynamics: Introduction

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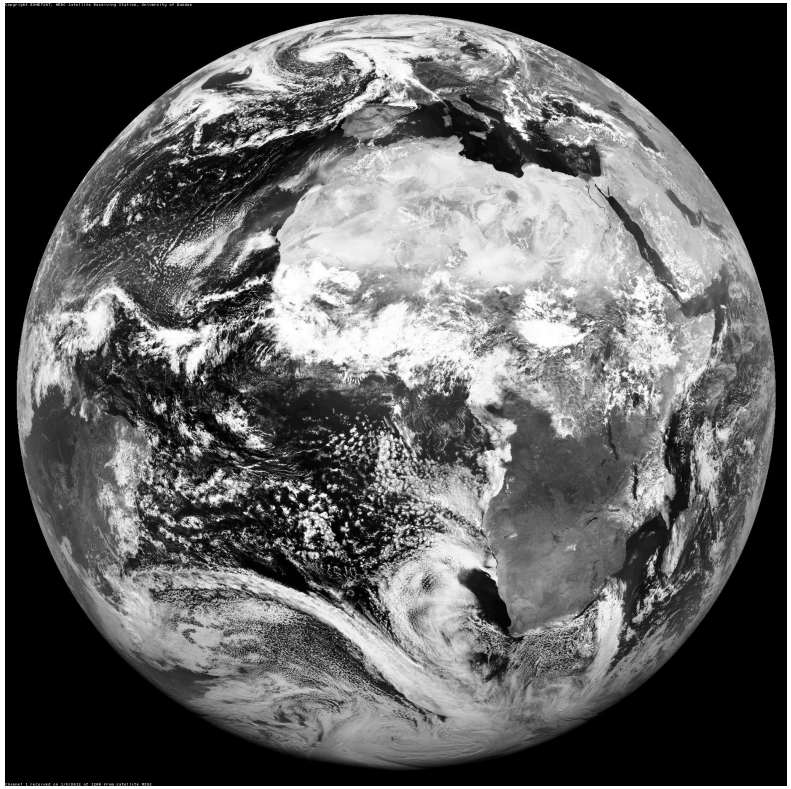
M1 ENS

Atmosphere: space-view



Courtesy: NASA

Visible in clouds - (unperfect) tracers : extratropical depressions, equatorial easterly waves and emerging tropical storm, inertia-gravity waves

Ocean: similar, but not visible without tracers.

General observations

Atmosphere and ocean: fluid-dynamics systems

- on the rotating ($\sim$) sphere
- with stratification due to gravity
- with non-trivial bottom (atmosphere, ocean) and lateral (ocean) boundaries
- with multiple phases and phase transitions (water vapor, liquid water, ice)

Typical scales

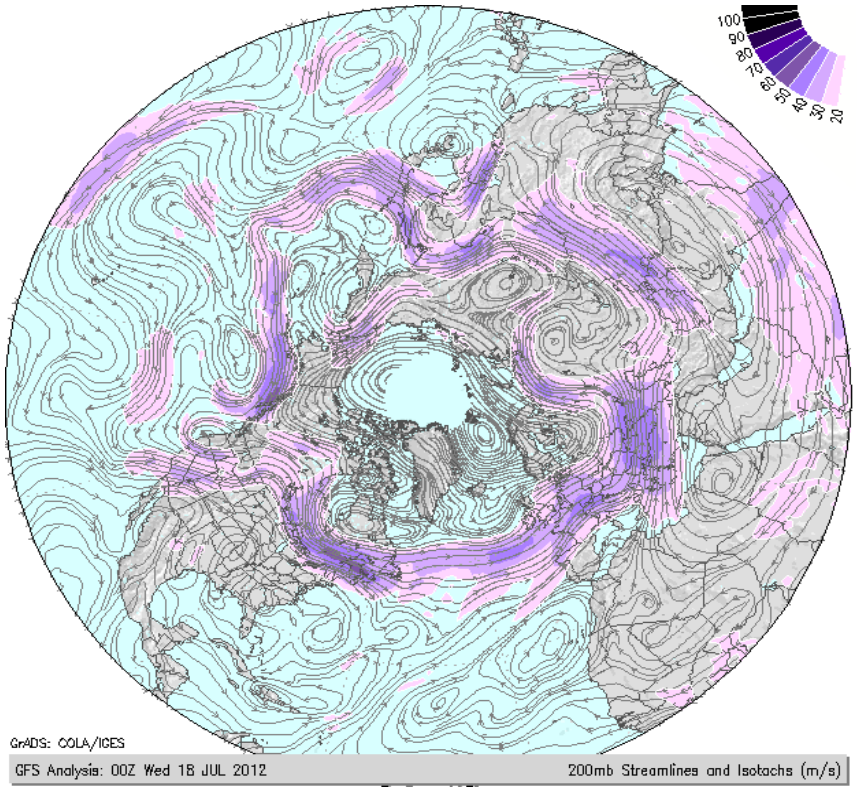
Atmosphere:

- Planetary (general circulation $\mathcal{O}(10000\,km)$
- Synoptic (weather systems) $\mathcal{O}(1000\,km)$
- Meso-scale (thunderstorms) $\mathcal{O}(10\,km)$
- Micro-scale (weather at the airport) $\mathcal{O}(10-100\,m)$

Ocean:

- Planetary (general circulation $\mathcal{O}(1000-10000\,km)$
- Meso-scale (Gulf-stream rings) $\mathcal{O}(100\,km)$
- Sub-Mesoscale (coastal phenomena) $\mathcal{O}(1-10\,km)$
- Small-scale (swell) $\mathcal{O}(10-100\,m)$

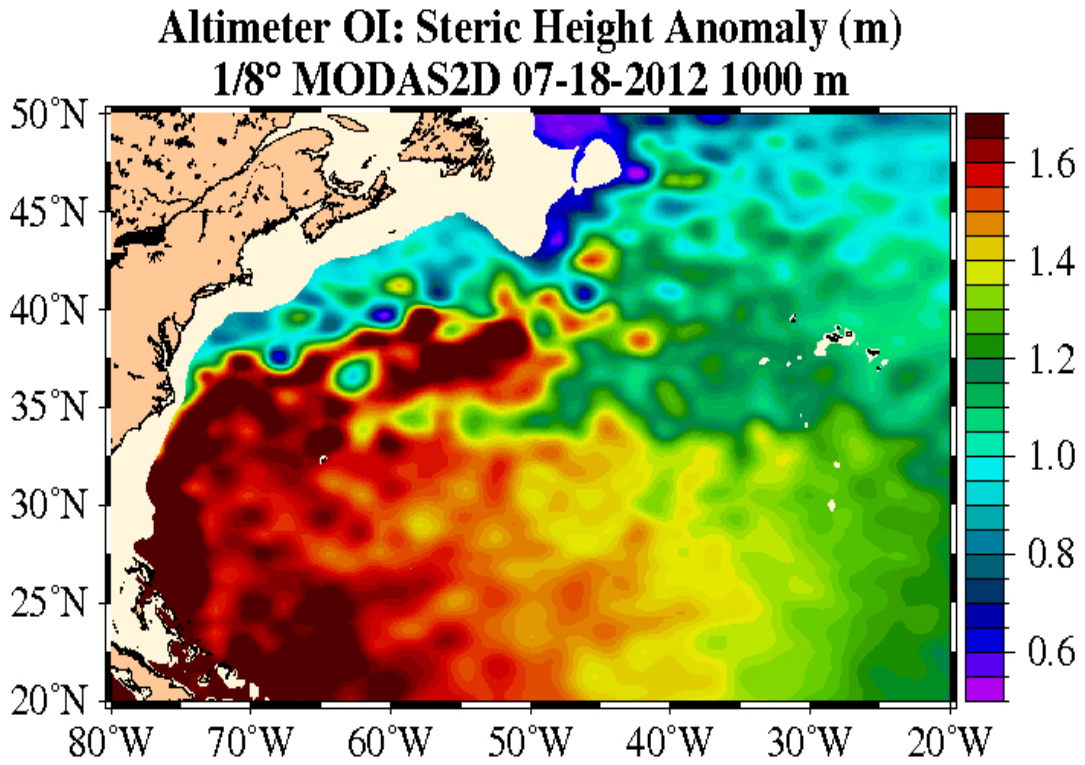
Upper tropospheric jet



Courtesy: COLA/NOAA

Mid-latitude jet-stream in the Northern Hemisphere as follows from the analysis in a general circulation model. Streamlines and modulus of velocity (colors).

Gulf-stream



Courtesy: US Navy

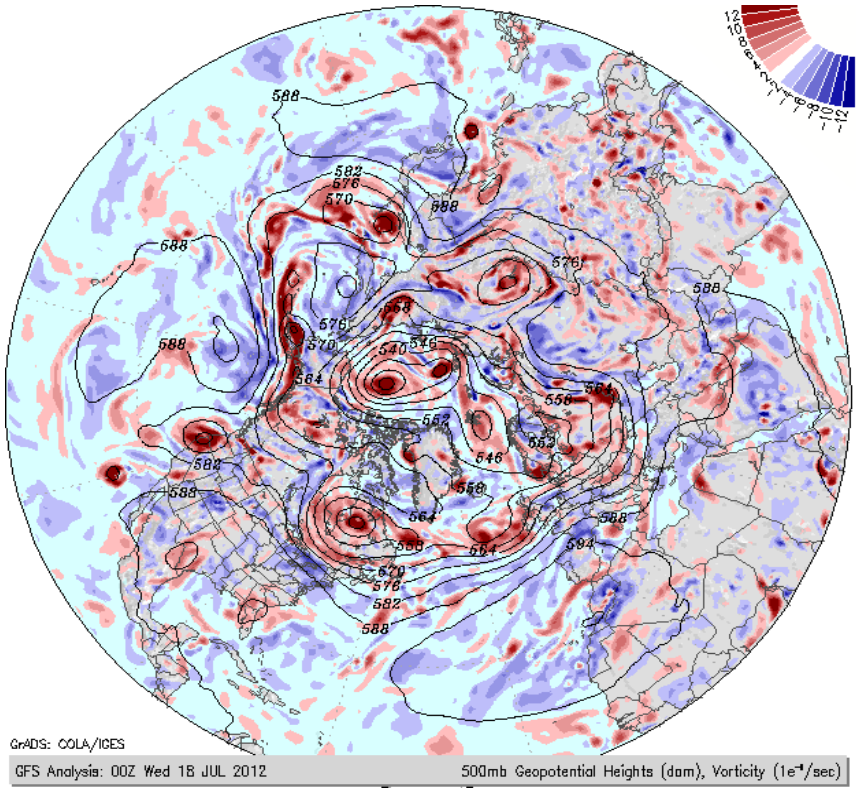
Gulf-stream as seen in the sea-surface height anomaly (colors) observed by satellite. See geostrophic balance in the main course for the relation between height and velocity.

Jets on other planets

Courtesy: NASA

Alternating jet-streams in Jovial atmosphere as seen by Juno mission. As in previous images, eddies are produced by instabilities of the jets.

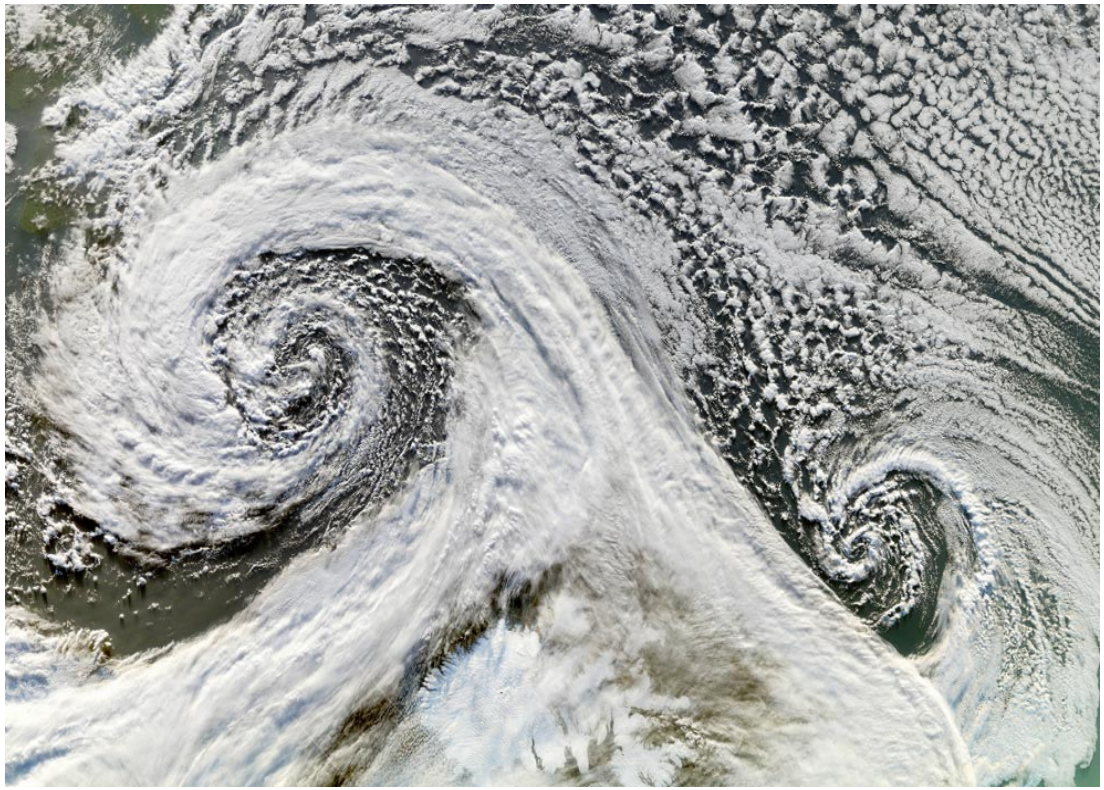
Tropospheric vortices in data



Courtesy: COLA/NOAA

Tropospheric eddies in the Northern Hemisphere as follows from the analysis in a general circulation model at 500 $mb \approx 4.5\,km$ altitude. Colors: relative vorticity (curl of the horizontal velocity). *Red*: cyclones, *Blue*: anticyclones.

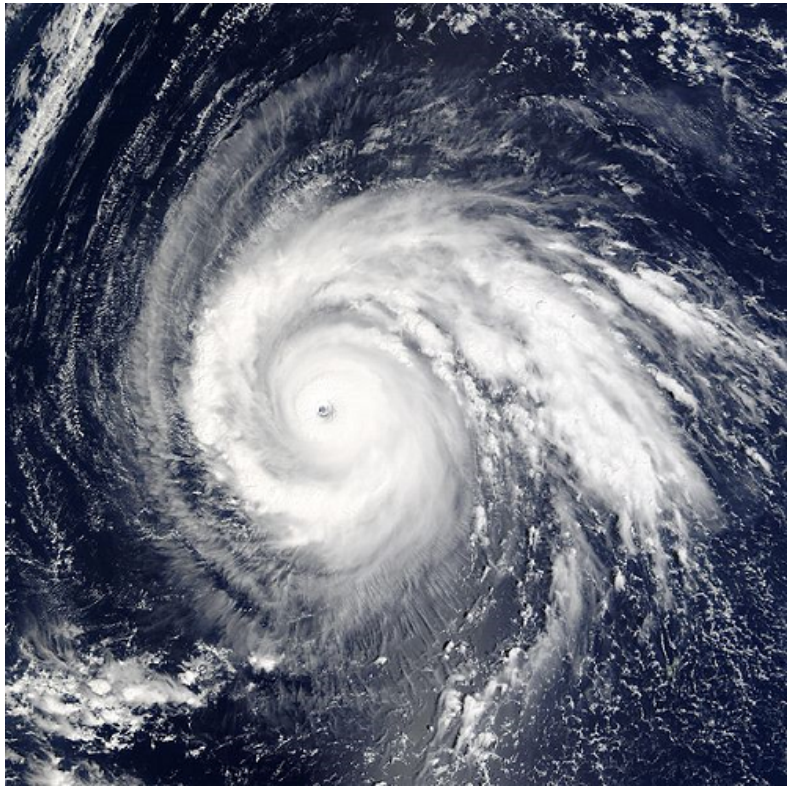
Tropospheric vortices in satellite images



Courtesy: NASA

Double cyclone in the Northern hemisphere.

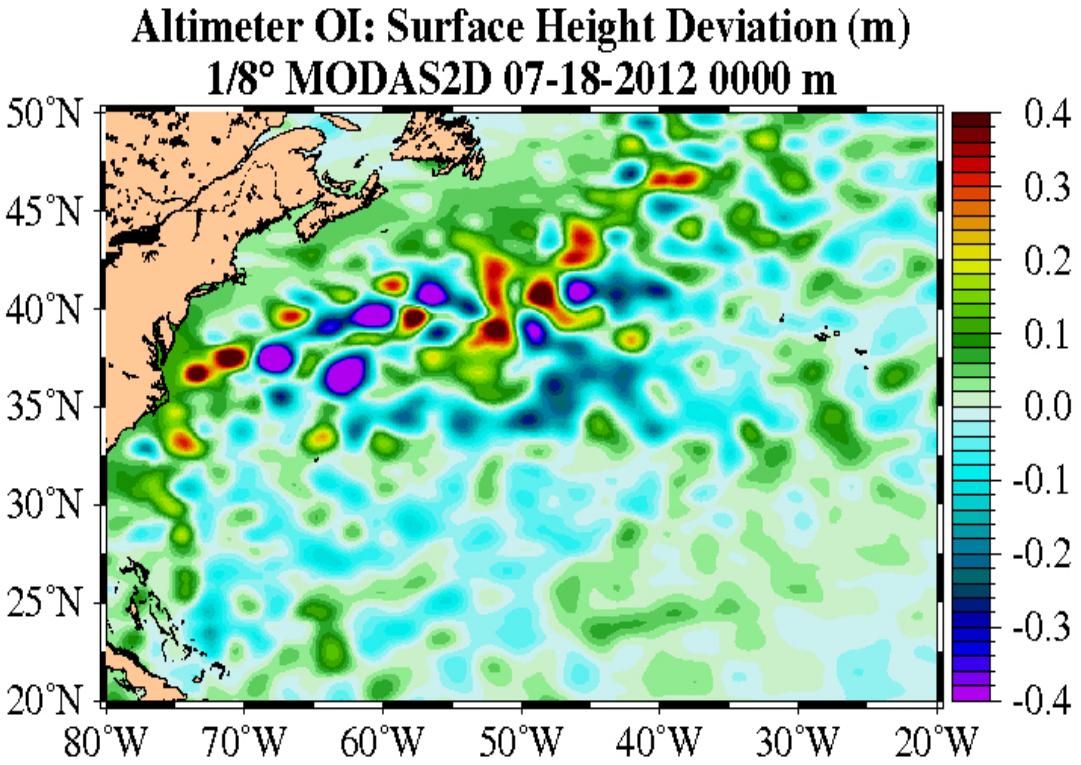
Tropical cyclones



Courtesy: NOAA

Tropical cyclone - intense sub-synoptic scale tropospheric vortex.

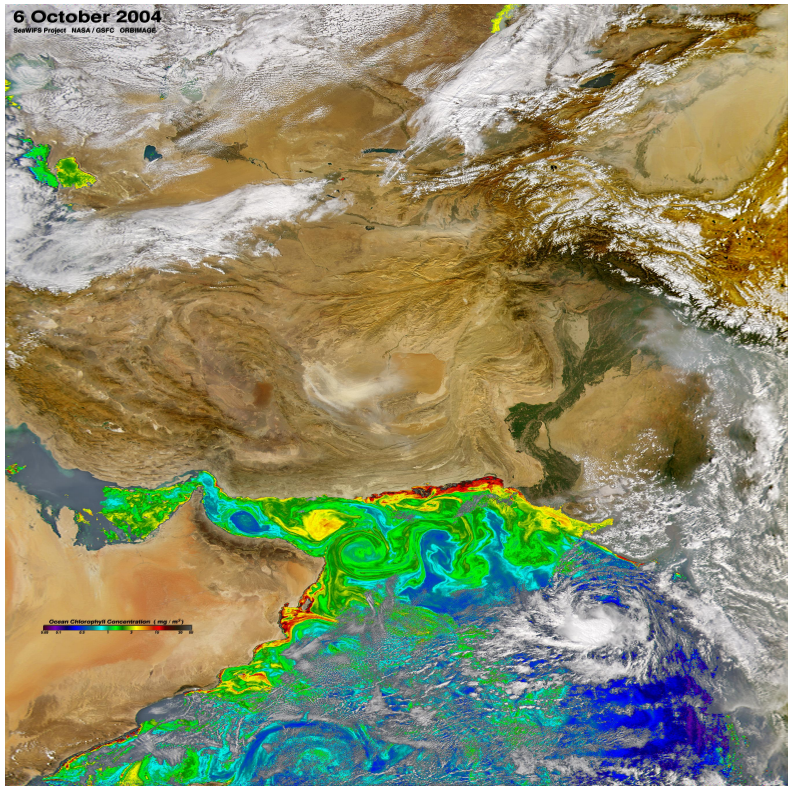
Gulf-stream rings



Courtesy: US Navy

Gulf-stream vortices as seen in the sea-surface height anomaly deviation (colors) observed by satellite. See geostrophic balance in the main course for the relation between height and velocity.

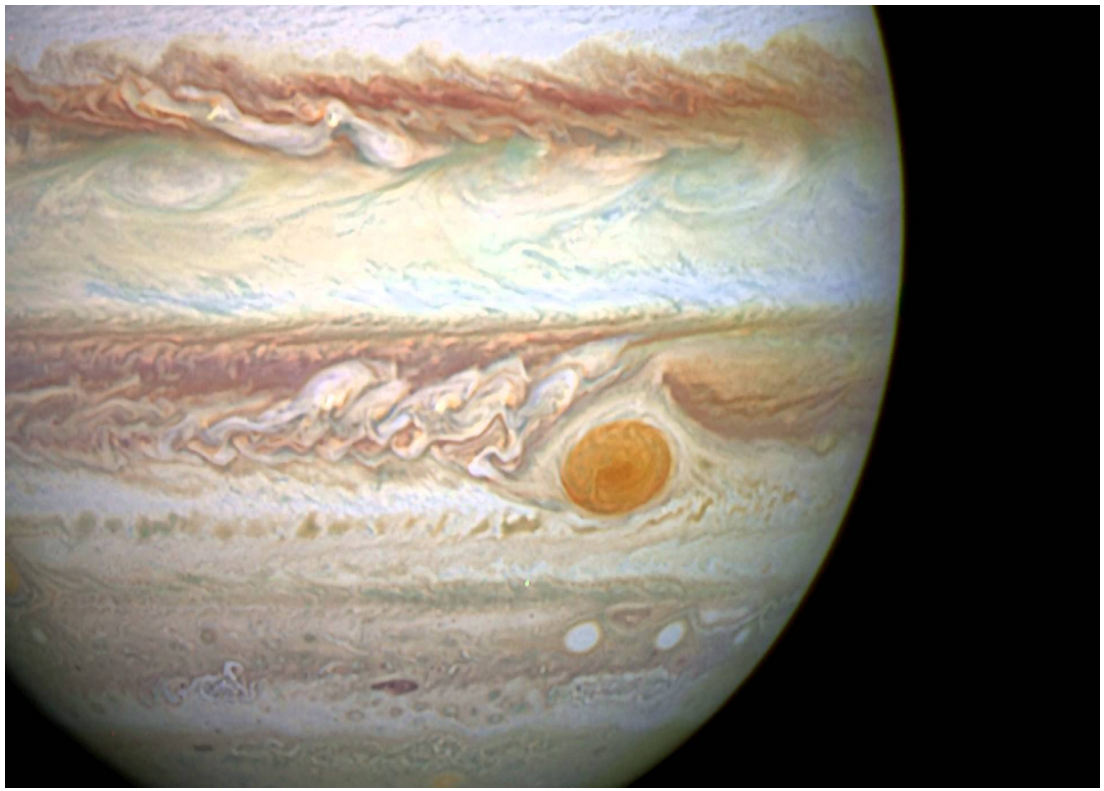
Vortices in Arabian see



Courtesy: US Navy

Vortices in Arabian see as seen in the plankton bloom (false colors).

Vortices in the the atmospheres of other planets



Courtesy: NASA

Great Red Spot in Jovial atmosphere - a quasi-stationary anticyclonic vortex, as seen by Juno mission.

Internal inertia-gravity wave in the Andaman sea

Courtesy: NOAA

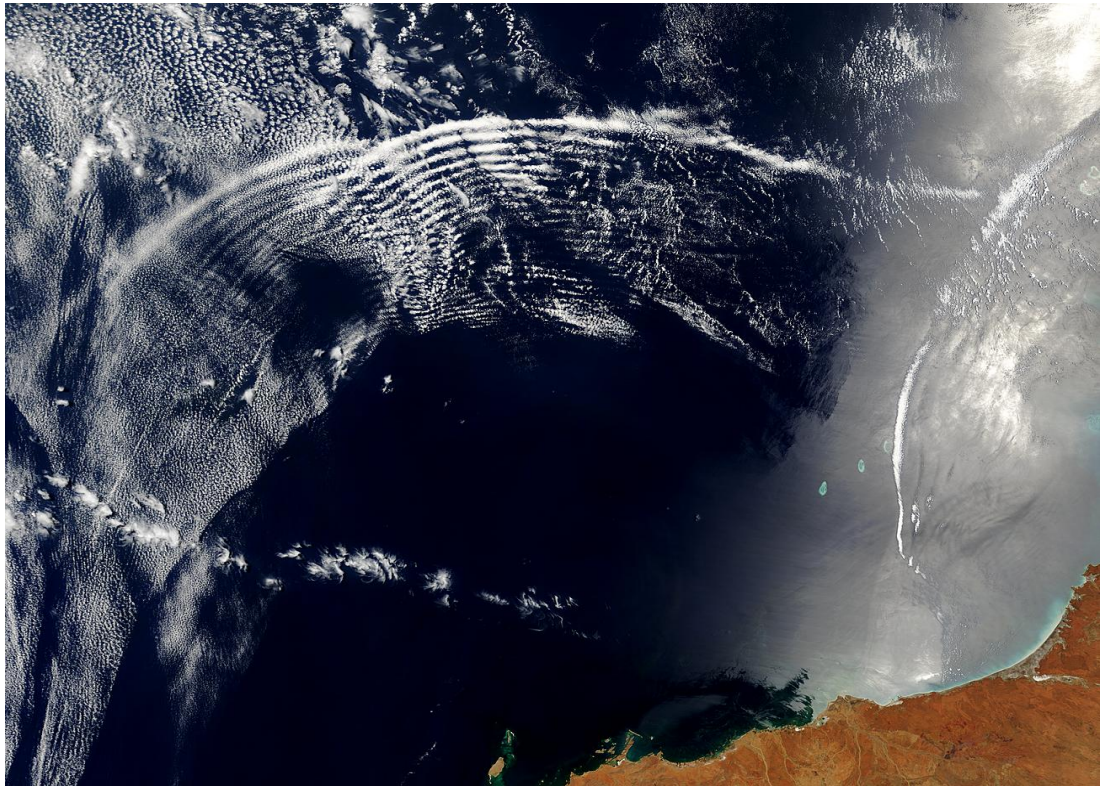
Large-scale internal wave as seen in the satellite image.

Internal inertia-gravity wave in Mediterranean

Courtesy: NASA

Large-scale internal wave produced by a tide in the Gibraltar straight as seen in the satellite image.

Atmospheric inertia-gravity waves near Australian coast



Courtesy: NASA

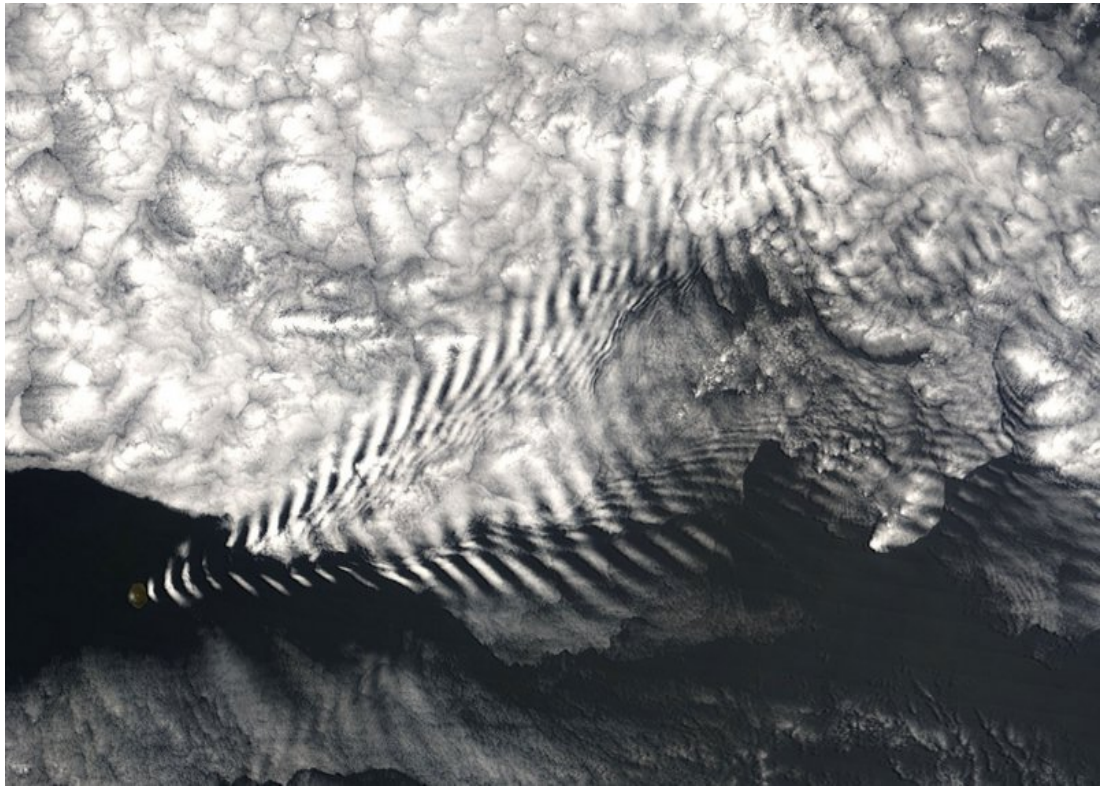
Traces of inertia-gravity waves in clouds.

“Morning glory” in Northern Australia

Courtesy: R. Grimshaw

A close view of the internal gravity wave in the atmosphere.

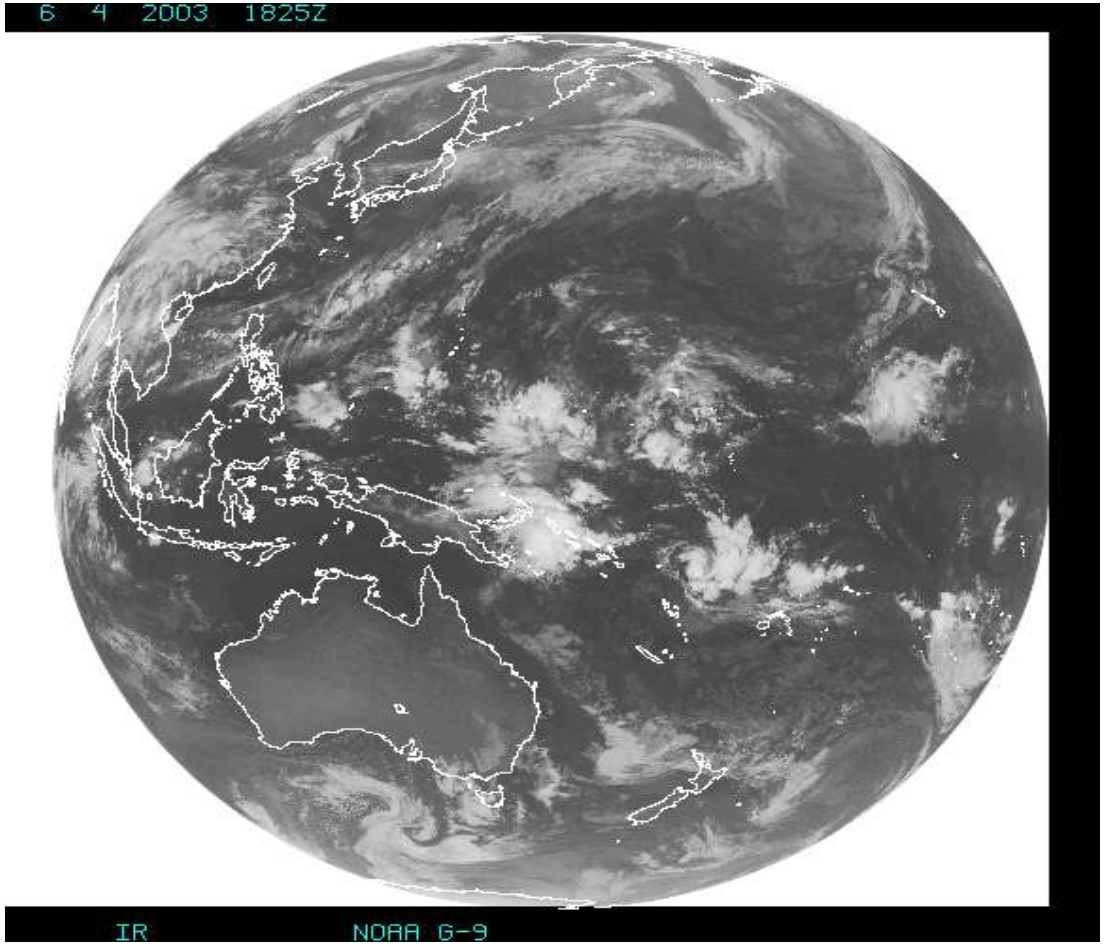
Atmospheric lee wave behind an island



Courtesy: NOAA

Lee wave as seen in the clouds behind an island.

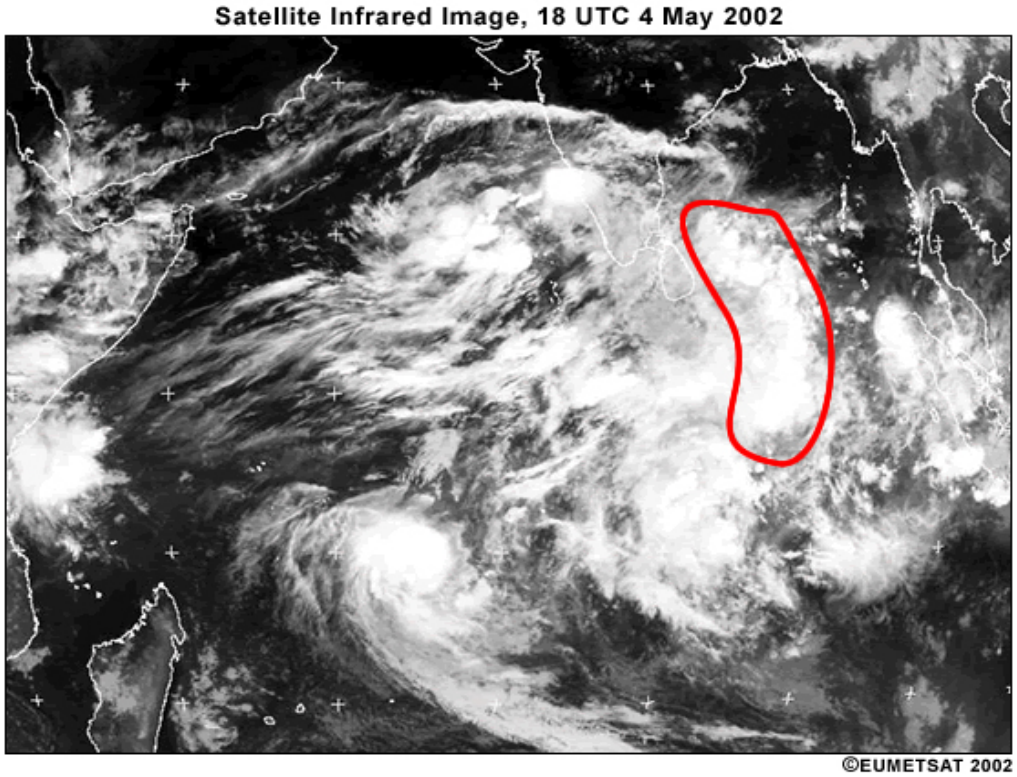
Atmospheric equatorial Rossby wave



Courtesy: NOAA

Equatorial Rossby-wave packet in the form of twin cyclones seen as cloud clusters at both sides of the Equator.

Atmospheric equatorial Kelvin wave



Courtesy: NOAA

Equatorial Kelvin-wave packet in the form of cloud arc (red) at the Equator.

Program:

- Maths refresher - need vector analysis, Fourier analysis, and PDEs
- Fluid dynamics refresher: GFD is fluid dynamics.
- Constructing the master model Primitive Equations(PE) and understanding its properties.
- Building simplified versions of PE: vertically averaged - shallow-water models, and/or time-averaged - quasi-geostrophic models.
- Understanding vortex and wave dynamics with them
- Acquiring basic notions of jet instabilities