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MS-GWaves

Transition from geostrophic flows to inertia-gravity waves in the spectrum of a differentially heated rotating annulus experiment.

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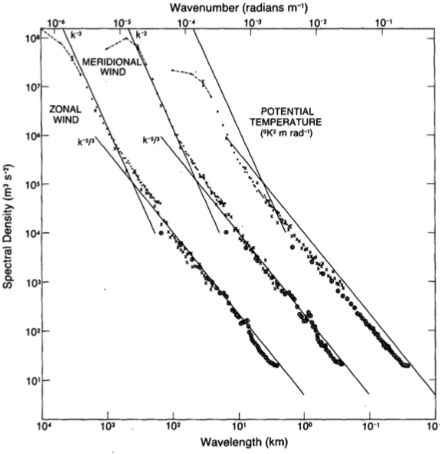
Atmospheric energy spectra

Nastrom and Gage (1985) provided the first comprehensive spectra of the zonal and meridional wind components and temperature measured near the tropopause level by commercial aircraft.

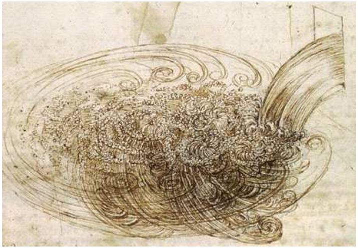


Two slopes in the spectra:

- Large (synoptic) scales k_h^{-3} well-explain by geostrophic turbulence theory (Charney 1971)
- Smaller (mesoscale) scales $k_h^{-5/3}$: still controversial

Among the various mechanisms proposed to explain the power law scaling at the mesoscales, the most invoked mechanisms are these two:

Turbulence



sketch of a turbulent flow by Leonardo da Vinci

Weakly nonlinear waves

representation of atmospheric gravity waves by Hines

In this work, we present an experimental investigation of the energy distribution between the large-scale balanced flow and the small-scale imbalanced flow:

- the differentially heated rotating annulus experiment is chosen for its capability of modelling gravity waves emitted by the baroclinic jet at the mid-latitudes (Rodda et al., 2019)
- the linear decomposition method applied by Callies, Ferrari, and Bühler (2014) to one-dimensional aircraft data is applied to the experimental data
- analogies and differences between the atmospheric and the experimental spectra are investigated

Atmospheric motions

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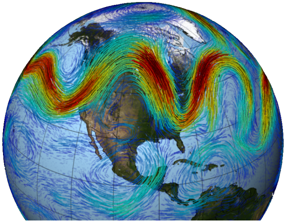
Atmospheric motions at the mid-latitudes can be divided into:

1. Synoptic-scale balanced motions

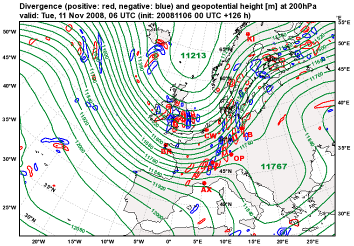
these develop as a consequence of the baroclinic instability of the westerly flow



Rapresentation of the mid-latitude jet stream from NASA

2. Mesoscale unbalanced motions

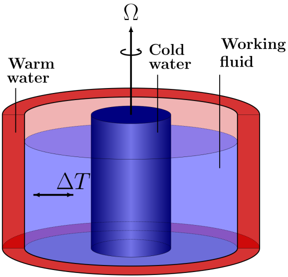
among which there are inertia-gravity waves (IGWs).

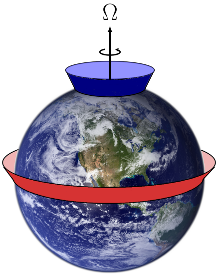


Maps of horizontal divergence from ECMWF

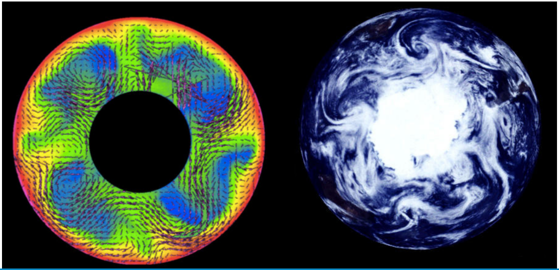
Experiment and atmosphere analogy

The atmospheric motions can be reproduced in the differentially heated rotating annulus laboratory experiment



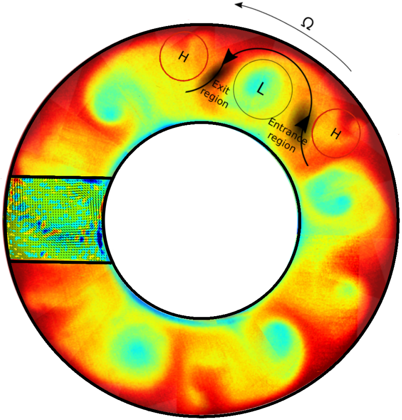


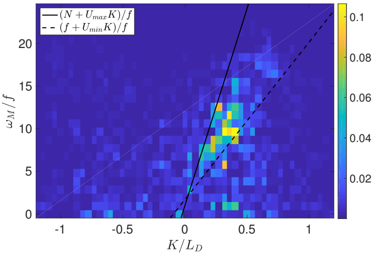
Sketch of the differentially heated rotating annulus experiment and analogy with Earth's atmosphere.



Left: surface temperature BTU experiment (courtesy M. Vincze). Right: satellite picture of the Earth from the south pole.

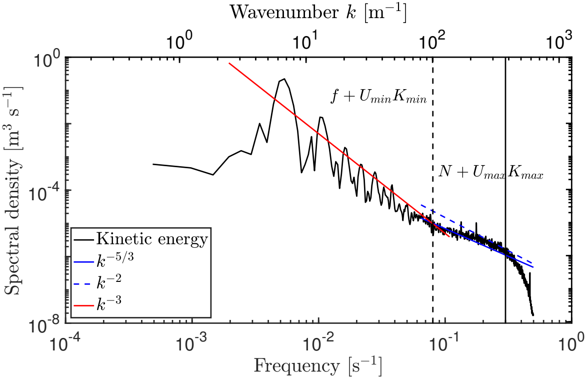
The combined plot of the surface temperature, showing the large-scale baroclinic wave, and the horizontal divergence (in the small inlet), showing small-scale wavelike features along the jet front and the wave crests are perpendicular to the flow.





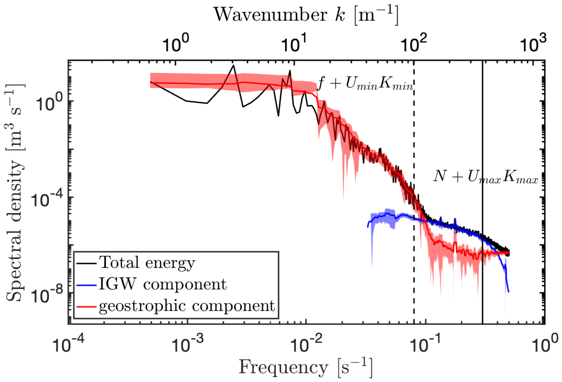
A plot in the frequency-wavenumber space shows that the region with the most significant amount of energy is included within the two curves marking the range for gravity waves.

The experimental kinetic energy spectra reveal the typical subdivision into two distinct regimes with slopes k^{-3} for the large scales and $k^{-5/3}$ for smaller scales. The flatter sub-range of the spectrum lies in the IGW frequency range.



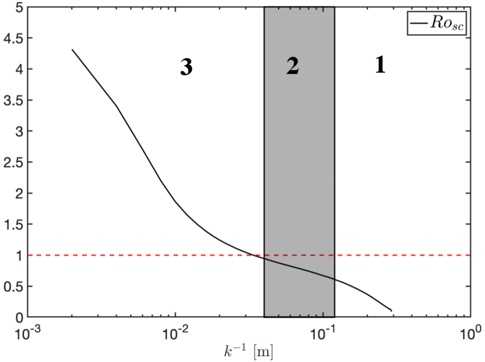
Kinetic energy spectrum BTU experiment

The total energy spectrum is decomposed into the geostrophic and inertia-gravity wave component.



The decomposition shows that the gravity wave component is dominating in the $-5/3$ range.

The scale-dependent Rossby number measures how linearity changes across the scales



1. balanced flow undergoes through a loss of balance by spontaneously emitting IGWs
2. dynamics dominated by nearly linear gravity waves
3. non-linear turbulent regime: forward energy cascade up to dissipation

1. Weakly nonlinear IGWs emitted from baroclinic jets, with characteristics similar to the atmospheric ones, are observed in the differentially heated rotating annulus experiment.

2. The experimental energy spectra show a striking similarity to the atmospheric spectra, proving how the differentially heated rotating annulus is not only an analog to the large-scale atmospheric flow, but can also be a useful tool to study multiple-scale processes in atmosphere-like flows.

3. Our investigation shows that at the large-scale of the mesoscale spectrum the gravity waves observed in the experiment cause a flattening of the spectra and provide most of the energy. At smaller scales, instead, the regime is more turbulent.

More details about the results presented here can be found in our preprint:

`http://arxiv.org/abs/2004.04052`

of the paper:

Costanza Rodda and Uwe Harlander (2020). *Transition from geostrophic flows to inertia-gravity waves in the spectrum of a differentially heated rotating annulus experiment.* Under review for JAS

MS-GWaves

- Rodda, Costanza et al. (2018). "Baroclinic, Kelvin and inertia-gravity waves in the barostrat instability experiment". In: *Geophysical & Astrophysical Fluid Dynamics*, pp. 1–32.
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- Rodda, Costanza and Uwe Harlander (2020). *Transition from geostrophic flows to inertia-gravity waves in the spectrum of a differentially heated rotating annulus experiment.* Under review for JAS.
- Nastrom, GD and K So Gage (1985). "A climatology of atmospheric wavenumber spectra of wind and temperature observed by commercial aircraft". In: *Journal of the atmospheric sciences* 42.9, pp. 950–960.
- Callies, Jörn, Raffaele Ferrari, and Oliver Bühler (2014). "Transition from geostrophic turbulence to inertia–gravity waves in the atmospheric energy spectrum". In: *Proceedings of the National Academy of Sciences* 111.48, pp. 17033–17038.