Equatorial waves in two-dimensional turbulence on the sphere

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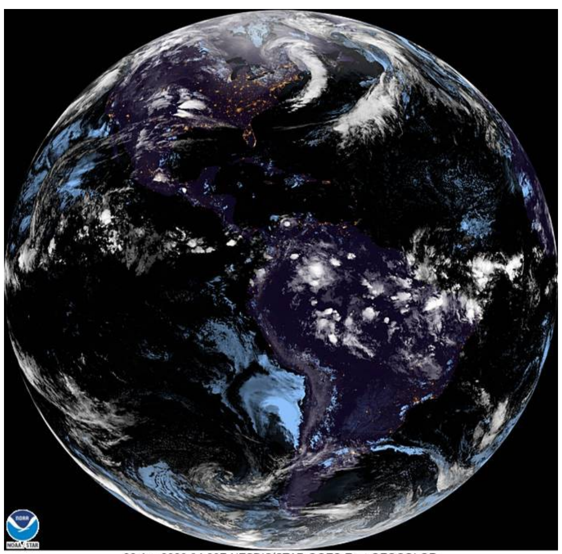

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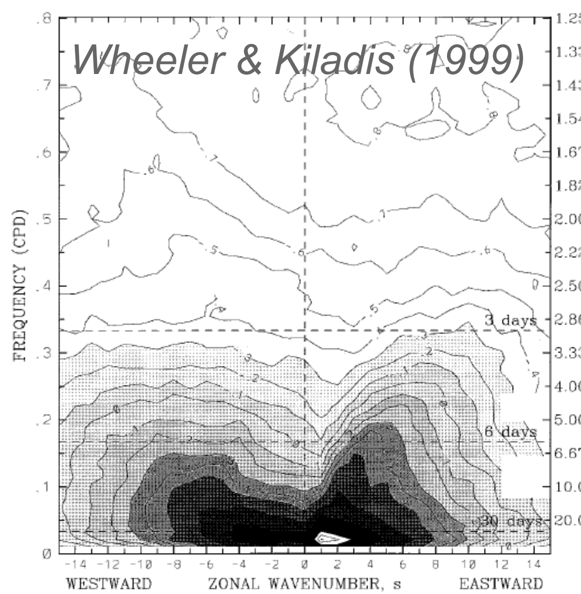
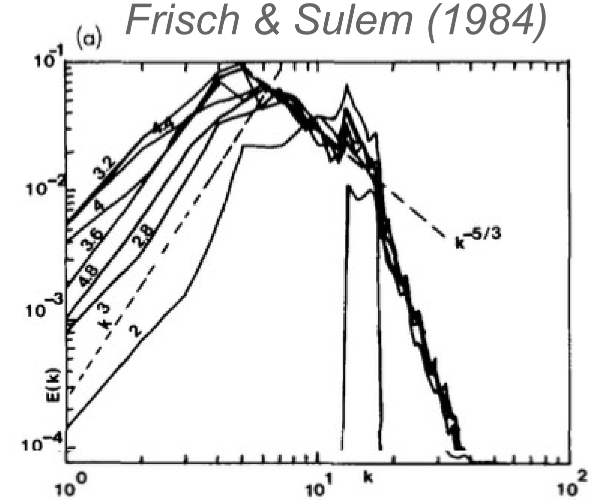
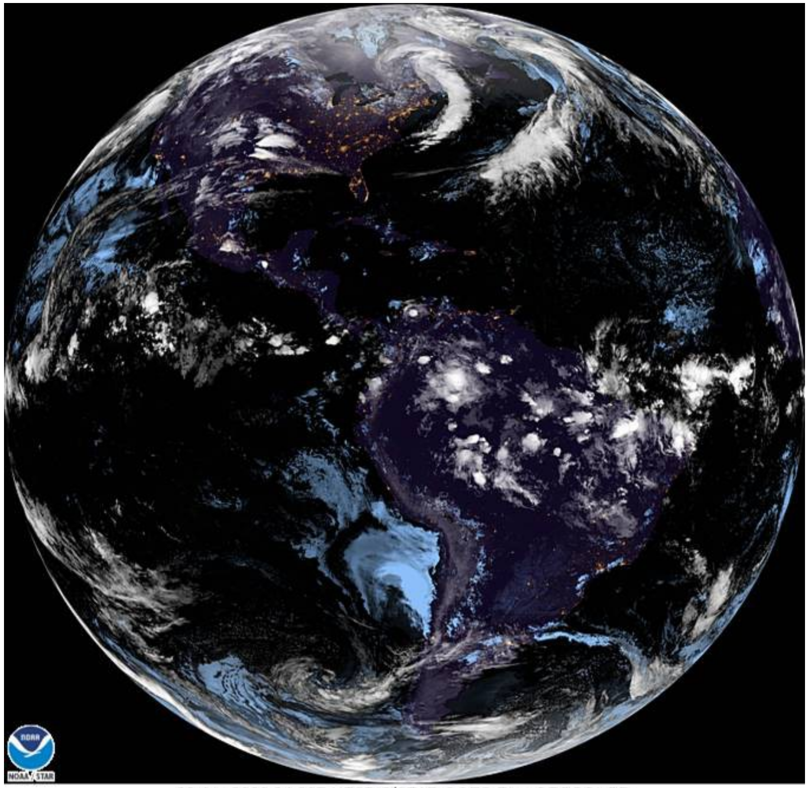


Frisch & Sulem (1984)



This work was conducted in a joint research project
between the Israeli Science Foundation & University Grants Commission, India.

Equatorial Waves on the Sphere



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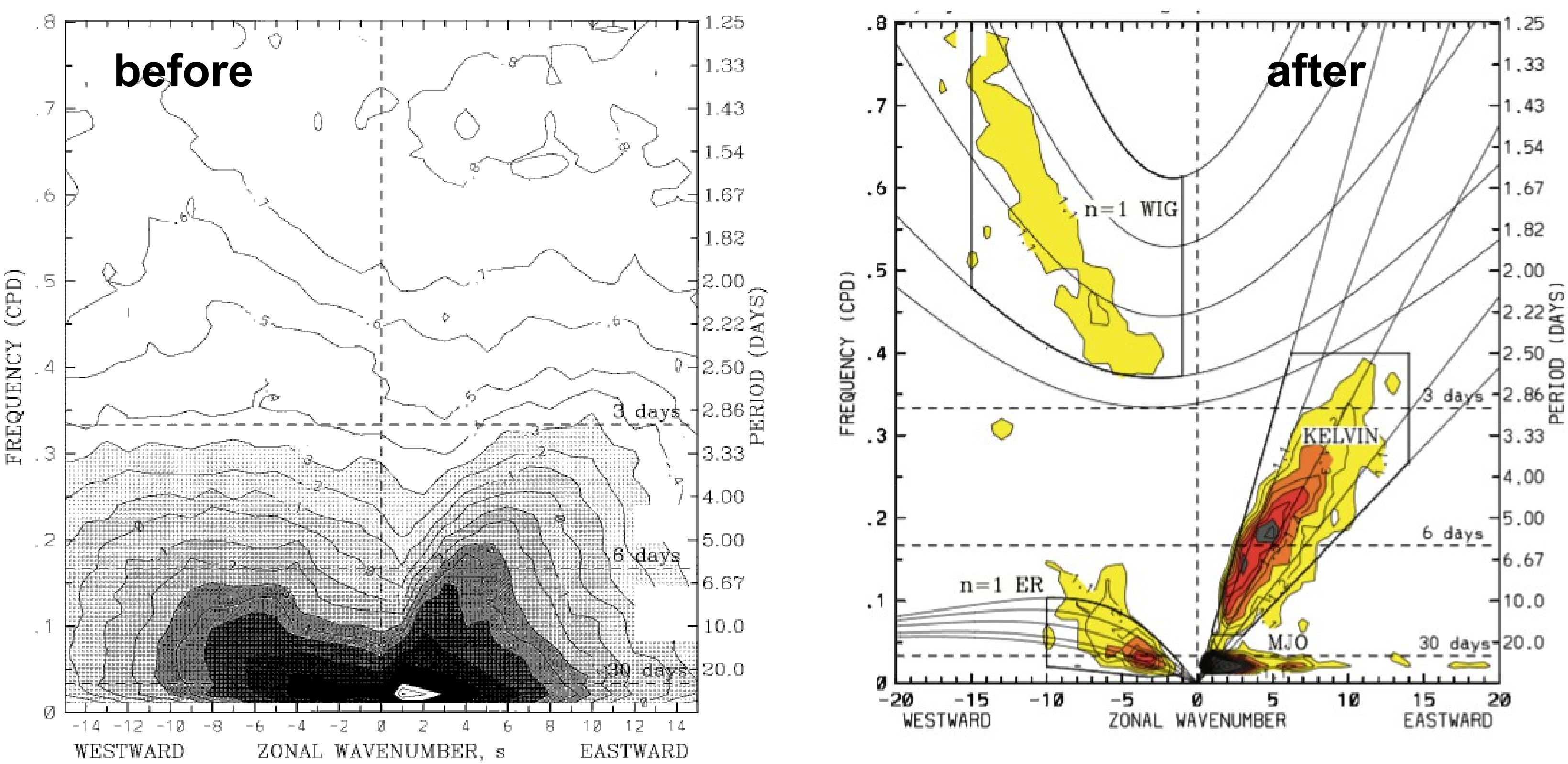
goes satellite observations

- Organization of clouds into clusters & their interaction with equatorial waves
- Can trigger Tropical Cyclones
- Affect the intensity of the monsoon
- Crucial for intra-seasonal prediction of weather in the extra-tropics

Work by Wheeler & Kiladis (1999)

Satellite observations exhibit **continuous spectra** & **low-frequency** modes – before removing background noise.



Maxima of variability in brightness temperature follow classical dispersion relations!

Approach to Moist Equatorial Waves

- Wheeler & Kiladis (1999) found strong signals in the brightness temperature over years of data with an hourly resolution. Those waves were embedded in a red-noise spectrum of atmospheric turbulence. Assuming that the WK diagrams show clusters of convective clouds: **How does the convection within these waves aggregate?**
- Groups around the globe are simulating planetary waves from either a direct (large-scale 1000 km) Matsuno-Gill forcing or approach self-aggregation with idealized wall bounded simulations resolving scales of 100 m. **What is happening in between?**
- In **moist fully non-linear shallow water** simulations, we can force each field separately with homogenous wave modes or a heterogenous structure. The moist simulations allow for a varying background saturation.

Does weak mesoscale forcing lead to equatorial waves?

Stochastic forcing of 2D Turbulence in Moist Shallow Water

Does weak mesoscale forcing lead to equatorial waves?

Vorticity $\zeta_t = -\nabla \cdot (\zeta \boldsymbol{v}) + f^{\zeta}$

Divergence $\delta_t = (\nabla \times \zeta \boldsymbol{v})_m - \Delta E + f^{\delta}$

Height $h_t = -\nabla \cdot (h \boldsymbol{v}) - L q^{+} / \tau_q + f^{h}$

Moisture $q_t = -\nabla \cdot (q \boldsymbol{v}) - q^{+} / \tau_q - q^{-} / \tau_e + f^{q}$

Dry Energy $E = gh + \dfrac{\|\boldsymbol{v}^2\|}{2}$

open system due to **asymmetry** and **nonlinearity**

$\tau_q = 0.1$ day $\qquad \tau_e = 10.0$ days

How do different forcings affect our simulations?

Role of moisture?

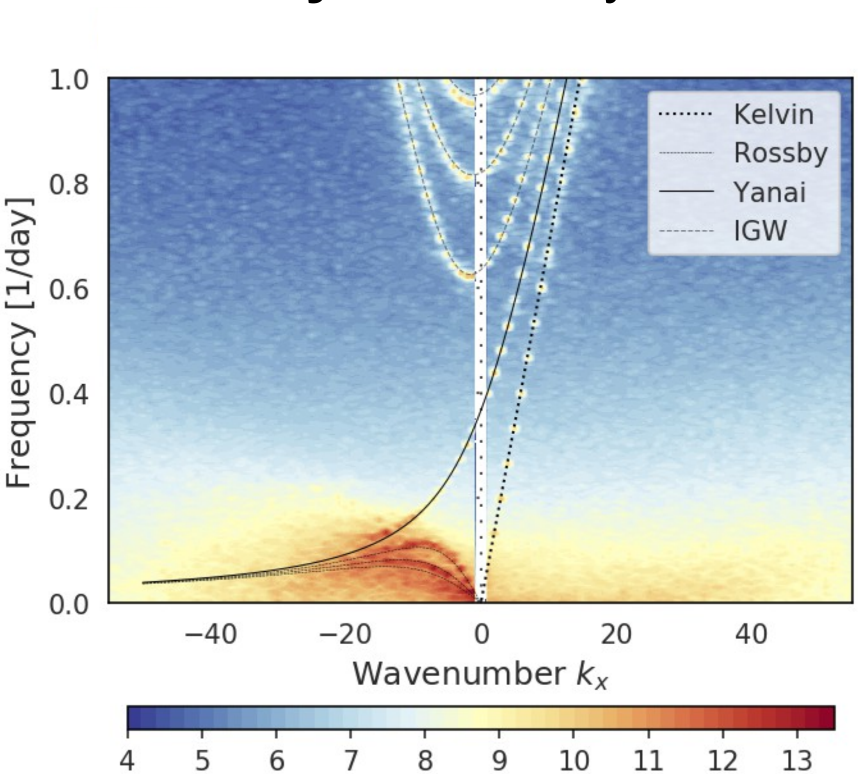
Moisture q is the deviation of the total available water vapor from saturation state q_s.

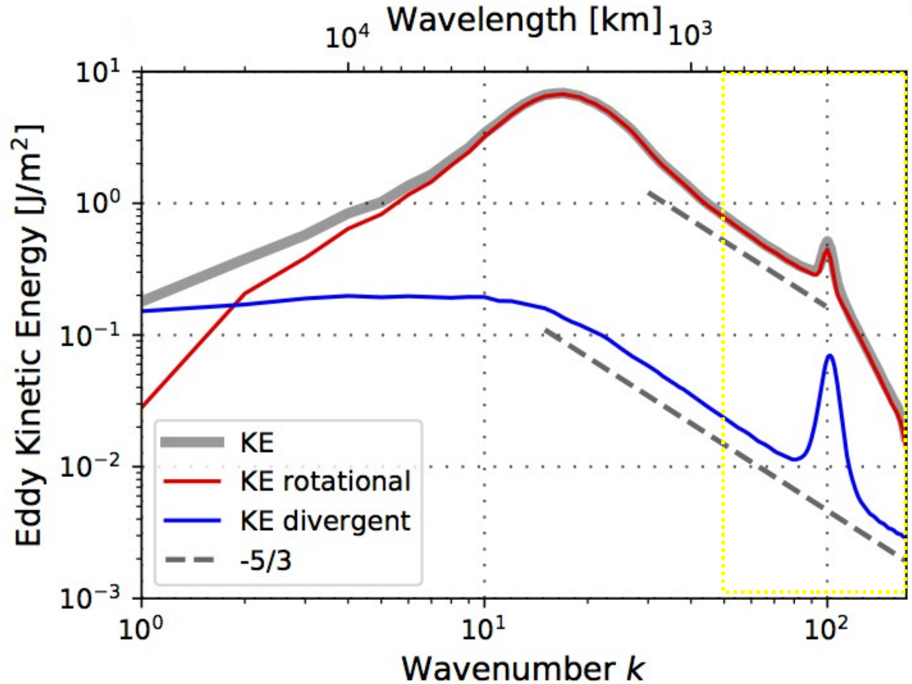
The code is based on a **dynamical core** developed by *Schaeffer et al. (2013, 2018).*

This is a collaboration funded by ISF between Israel & India.

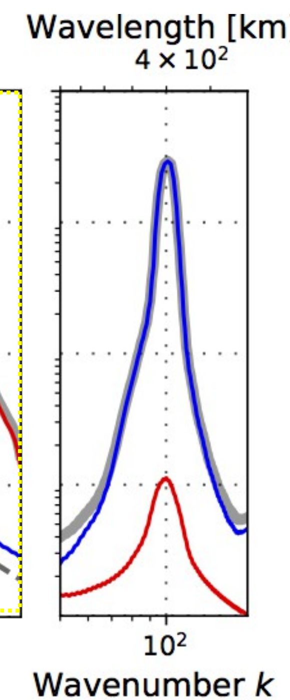
Equatorial Waves in a Turbulent Flow

Vorticity forced dry shallow water equations





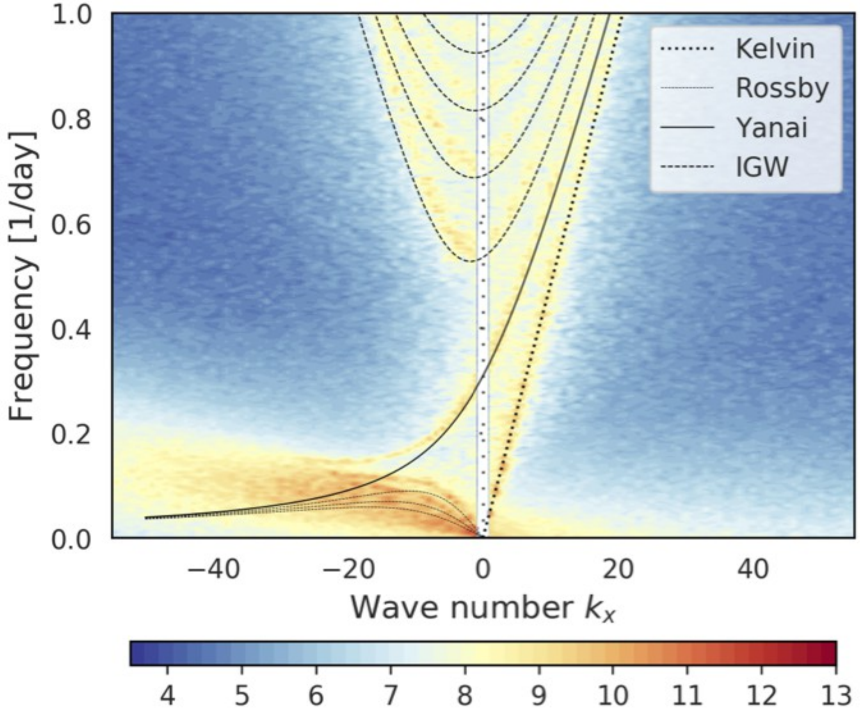
Divergence forced

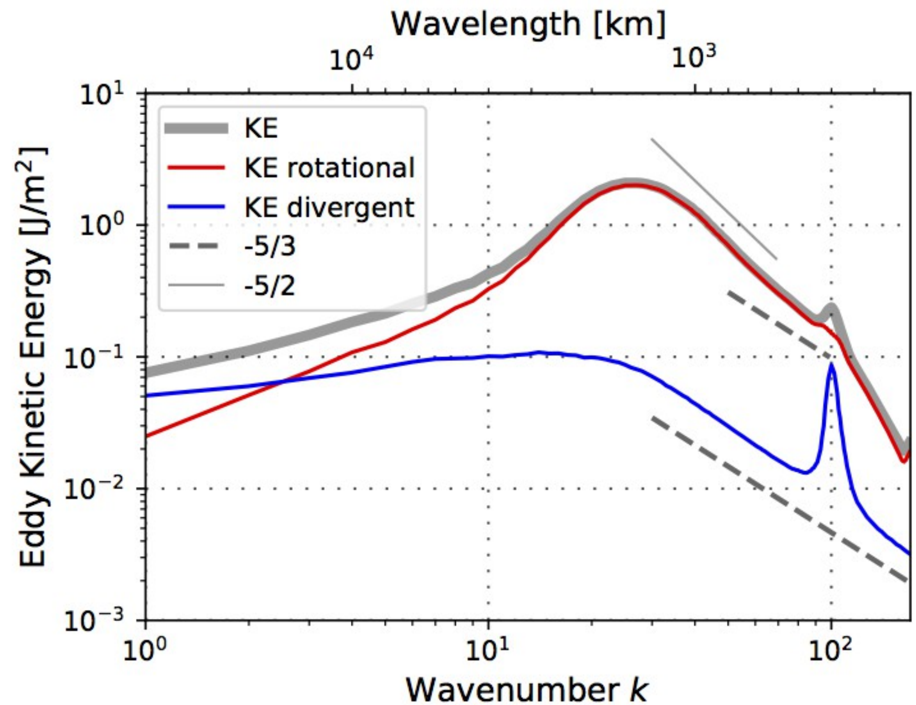


Forcing the dry as well as moist shallow water equations through vorticity can lead to a co-existence of equatorial waves & turbulence!

Equatorial Waves in a Turbulent Flow

Moisture forced shallow water equations





In the moist shallow water system, energy also cascaded upscale when forcing moisture.

Self-aggregation in a Turbulent Flow

Spectra of moisture variance on days 1, 40, 80, 160 & equilibrium state.

Vorticity forced moist shallow water equations

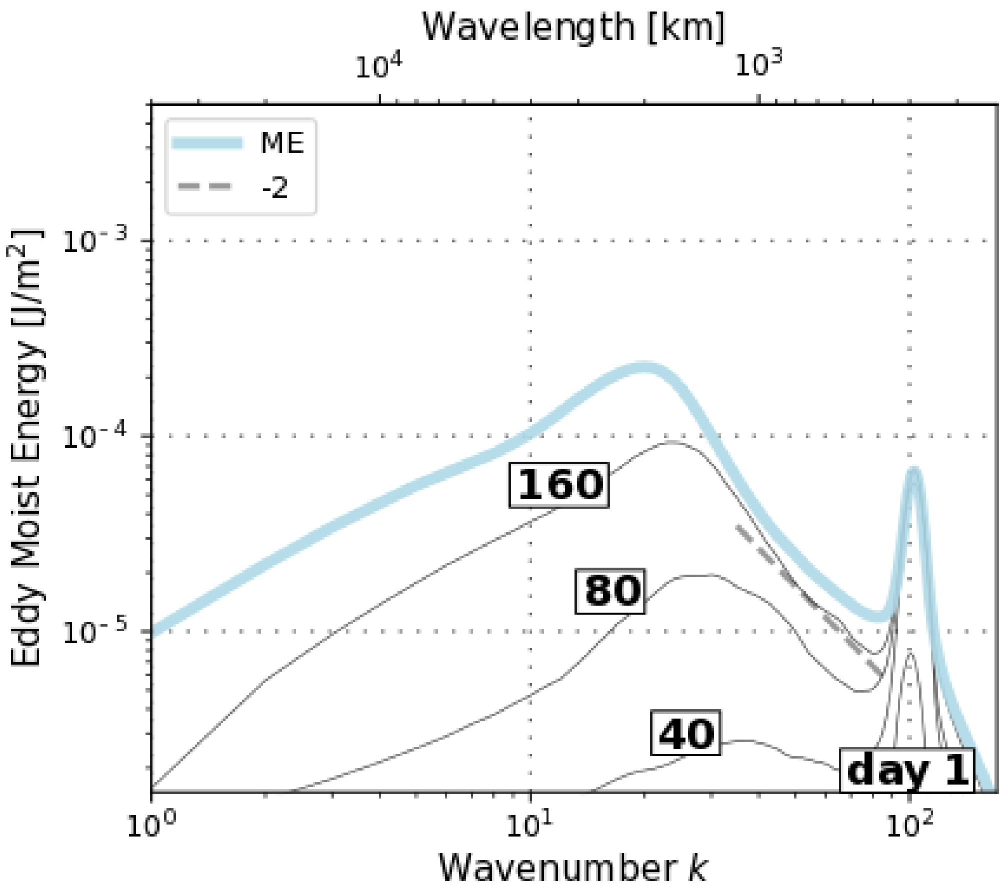
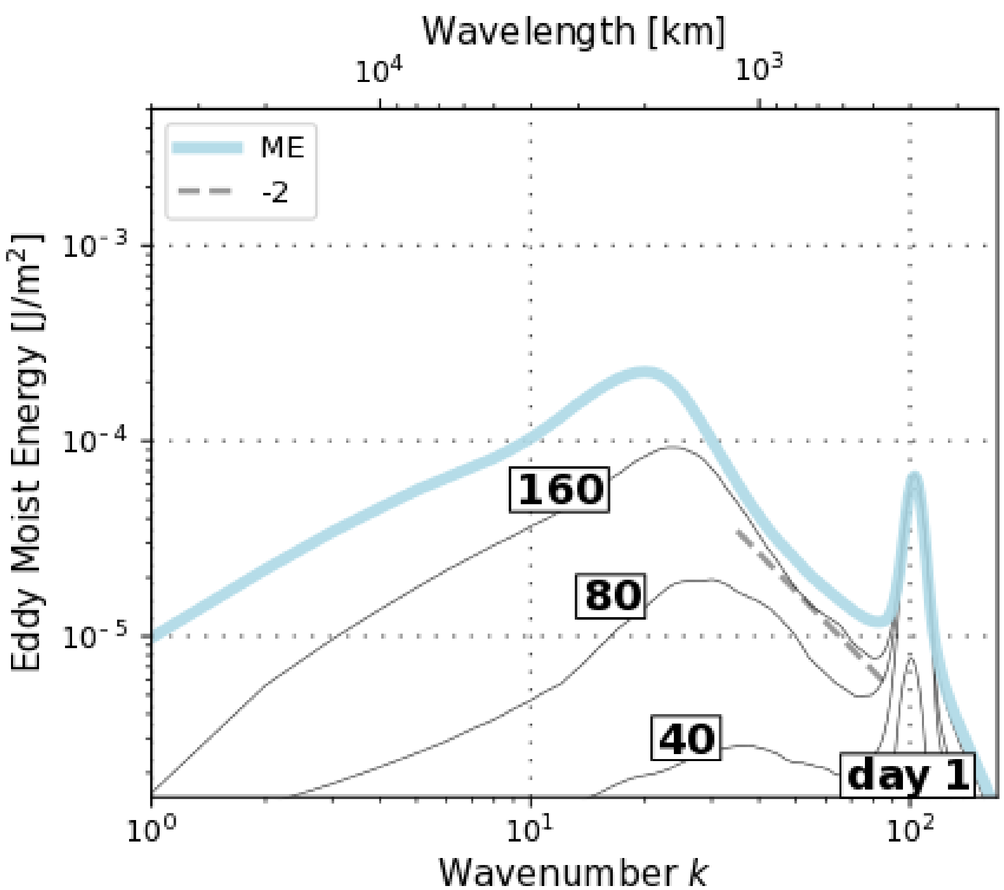


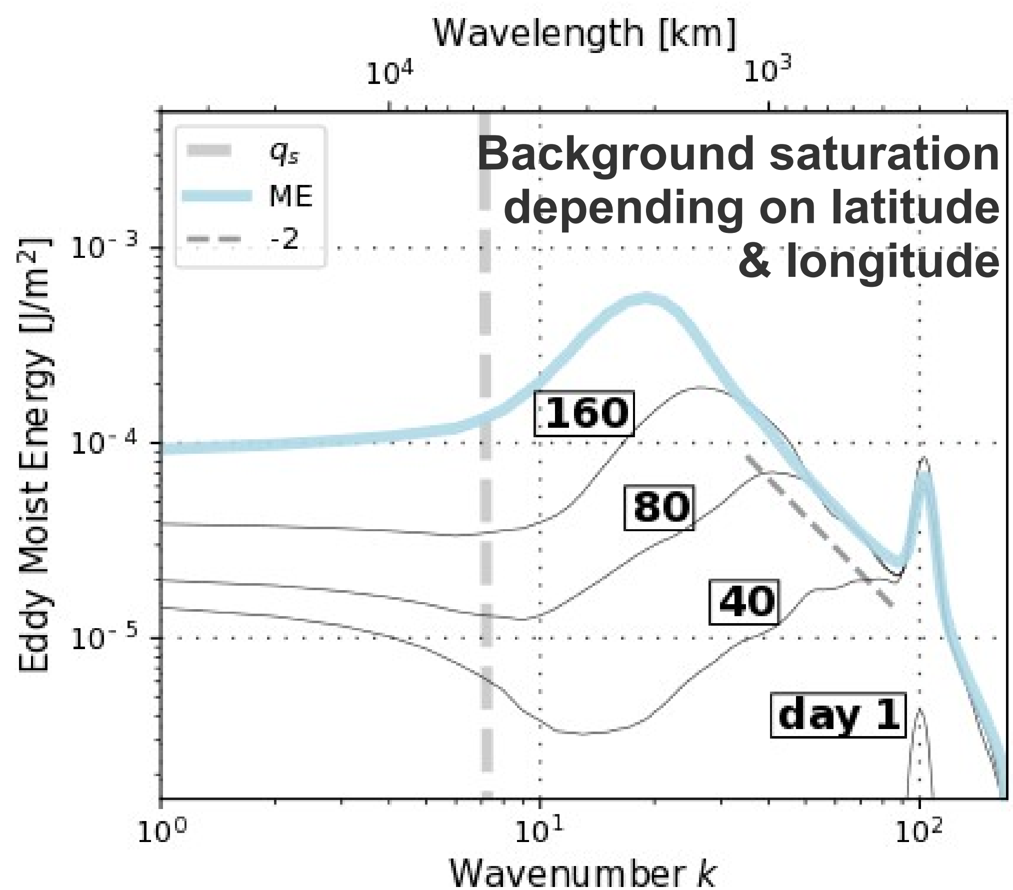
Photo by T. Pesquet, International Space Station, April 25th 2021

Moisture aggregates in fully developed turbulence.

Self-aggregation in a Turbulent Flow

Spectra of moisture variance on days 1, 40, 80, 160 & equilibrium state.





When saturation depends on latitude & longitude, planetary scale wave modes are excited more strongly.

Conclusions & Outlook

- A fully developed -5/3 upscale energy cascade forms up to the planetary scale, when **forcing vorticity** or **moisture** at the mesoscale!

- Also, **planetary waves** are excited that follow the theoretical dispersion relations, as energy propagates upscale!

- We further find **moisture aggregation** within fully developed **turbulence** following a self-similar -2 cascade!

- **Next step**: multi-layer simulations with stochastic forcing of tropical waves similar to Yang & Ingersoll (2013), but within a fully developed **moist baroclinc instability**.

Thank you for listening!

Schröttle, J., Suhas, D. L., Harnik, N., Sukhatme, J.: 'Turbulence and equatorial waves in moist & dry shallow water systems', Quarterly Journal Royal Meteorological Society (submitted, 2021) arXiv: 2104.12889