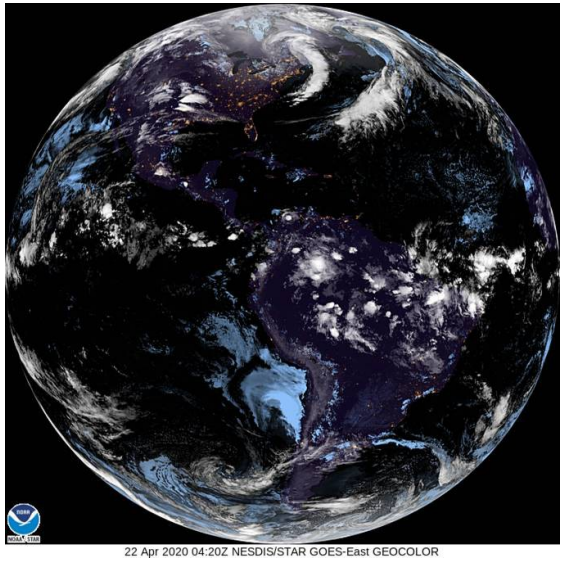
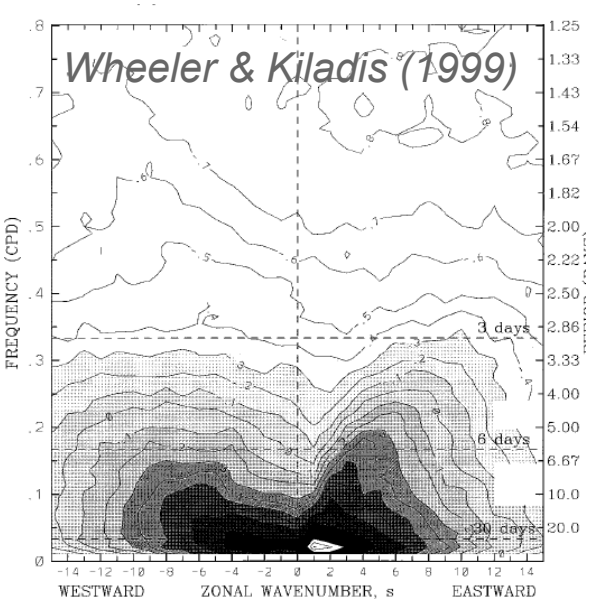
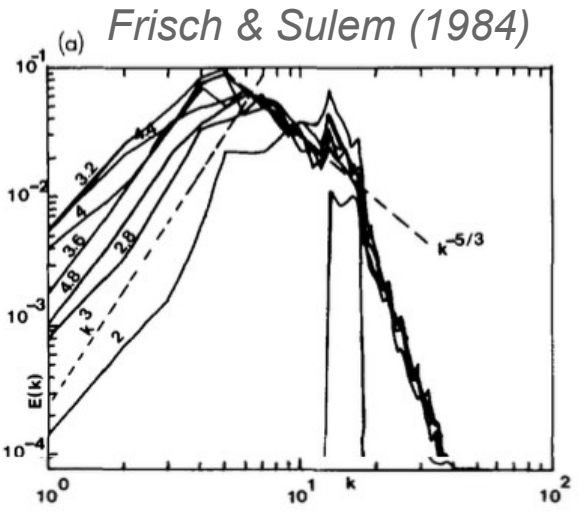
Superrotation in moist shallow-water turbulence

Josef Schröttle[1,6], D.L. Suhas[2,5], Nili Harnik[1], Yair Cohen[4], Jai Sukhatme[2,3]

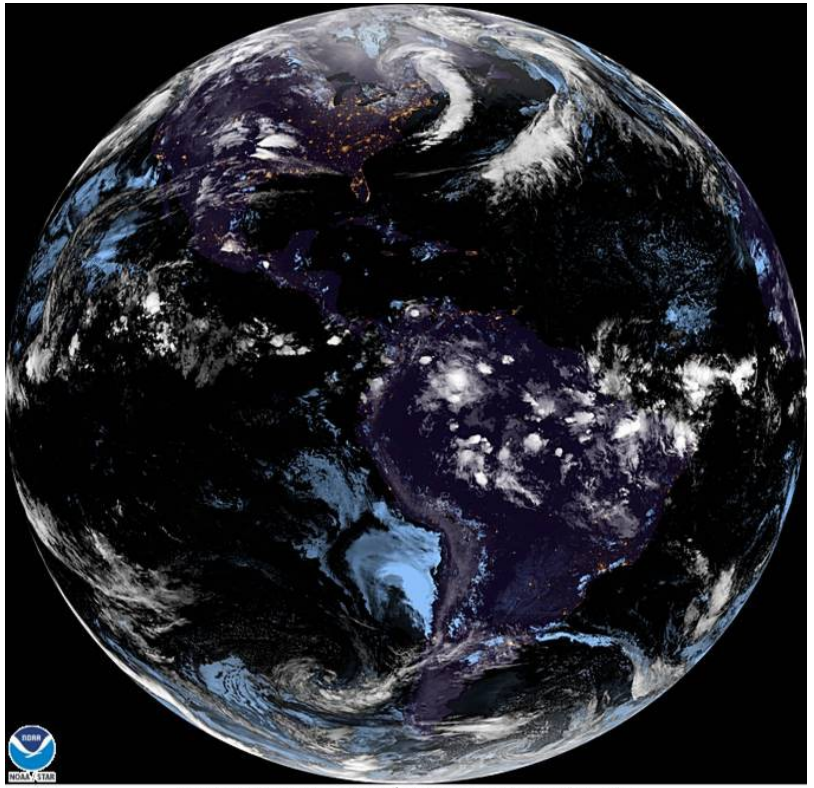
1) Department of Geophysics, School of Earth Sciences, Tel Aviv University, Israel
2) Centre for Atmospheric and Oceanic Sciences, Indian Institute of Science, Bangalore, India
3) Divecha Centre for Climate Change, Indian Institute of Science, Bangalore, India
4) California Institute of Technology and Jet Propulsion Laboratory, Pasadena, USA
5) Department of Earth and Planetary Science, University of California, Berkeley, USA
6) Satellite data assimilation & Destination Earth Team, ECMWF, Bonn, Germany







Equatorial Waves on the Sphere

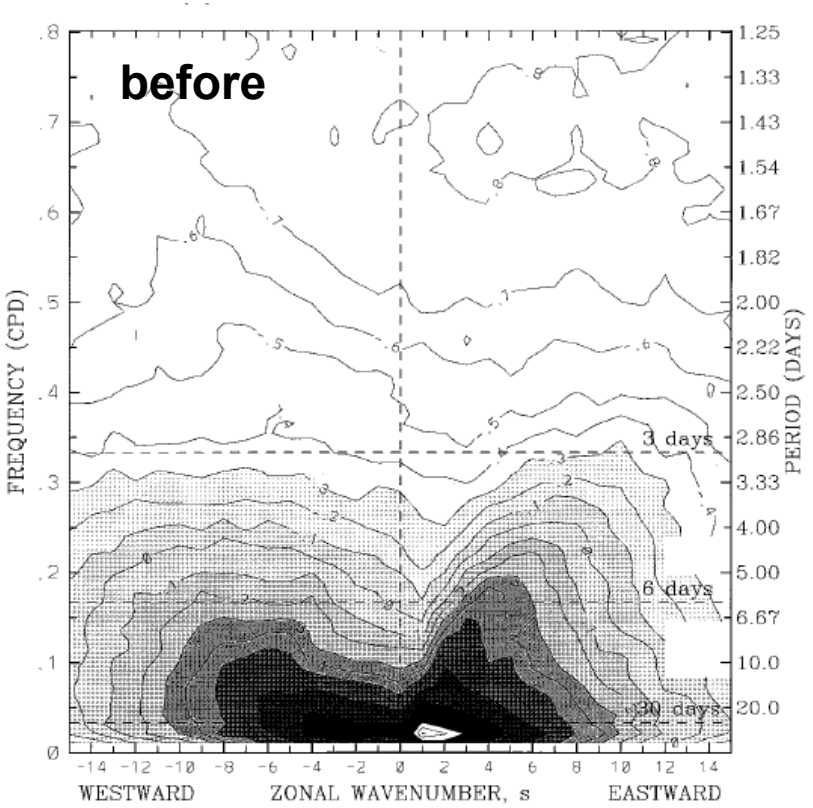


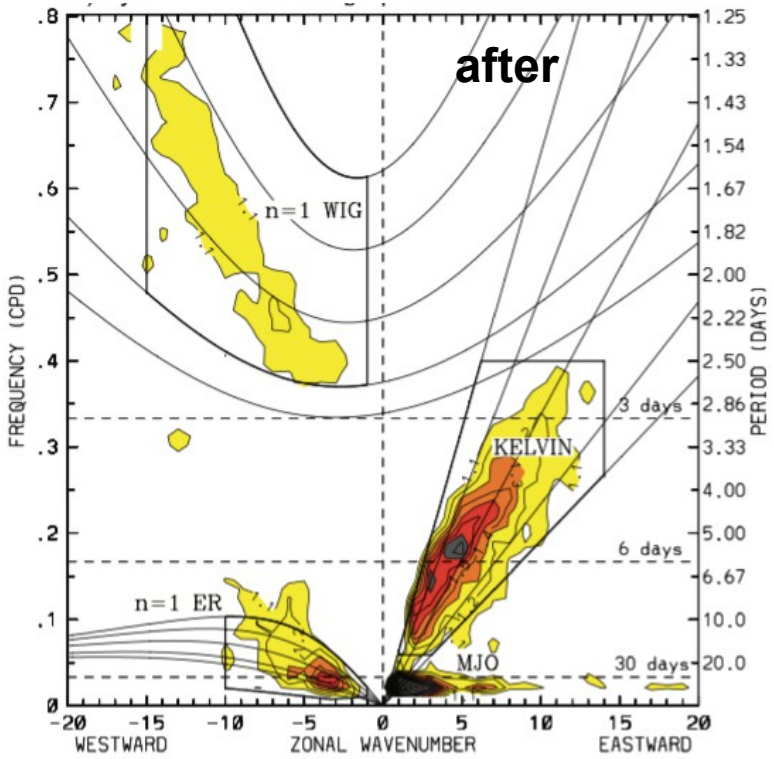
goes satellite observations

- Organize & interact with deep convection
- Can trigger Tropical Cyclones
- Affect the intensity of the monsoon
- Crucial for interseasonal 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!

Stochastic forcing of 2D Turbulence in Moist Shallow Water

How do smaller scales interact with equatorial waves?

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

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

What about unresolved physics?

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

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

Role of moisture?

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

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

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

The code is based on a **dynamical core** developed by *Schaeffer et al. (2013, 2018).* **Barotropic flow** by *Suhas & Jai (2015)* or in dry shallow water with stochastic forcing by *Suhas et al. (2017).*

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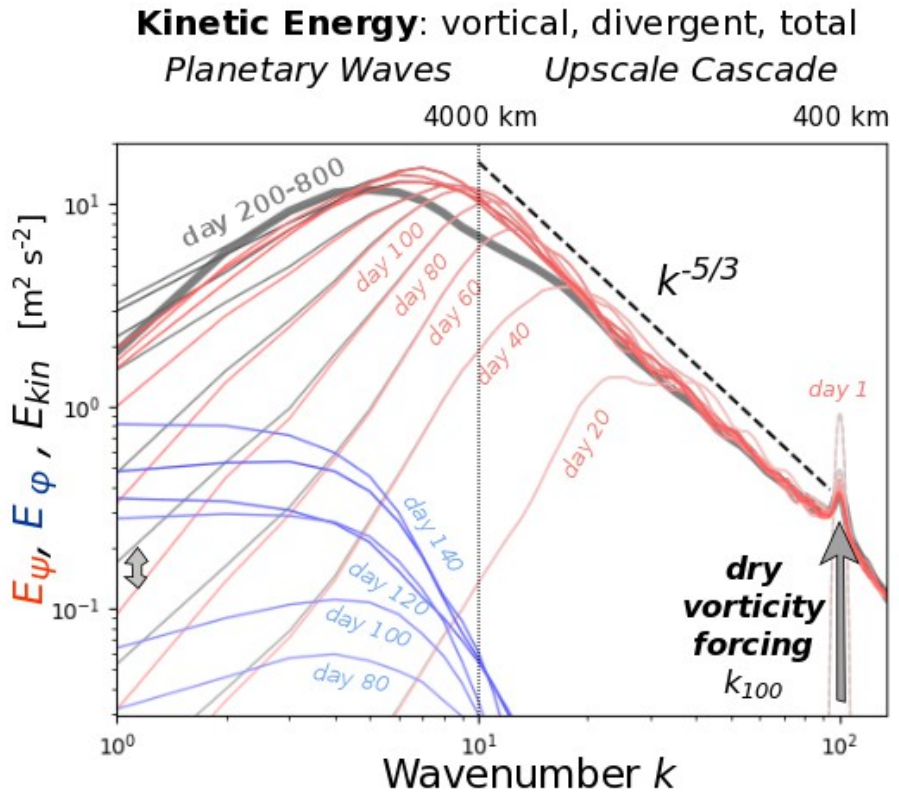
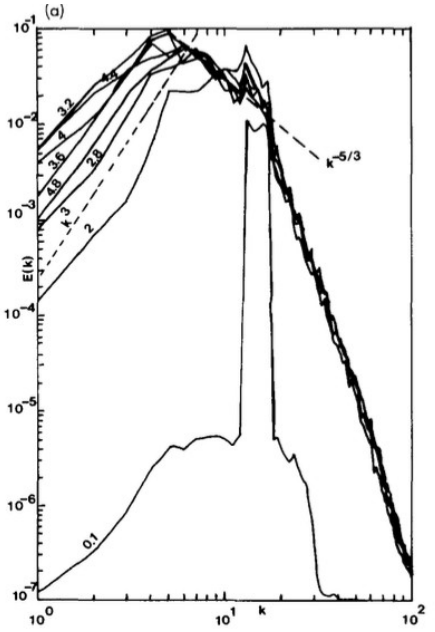
1) Upscale cascade in 2D turbulence

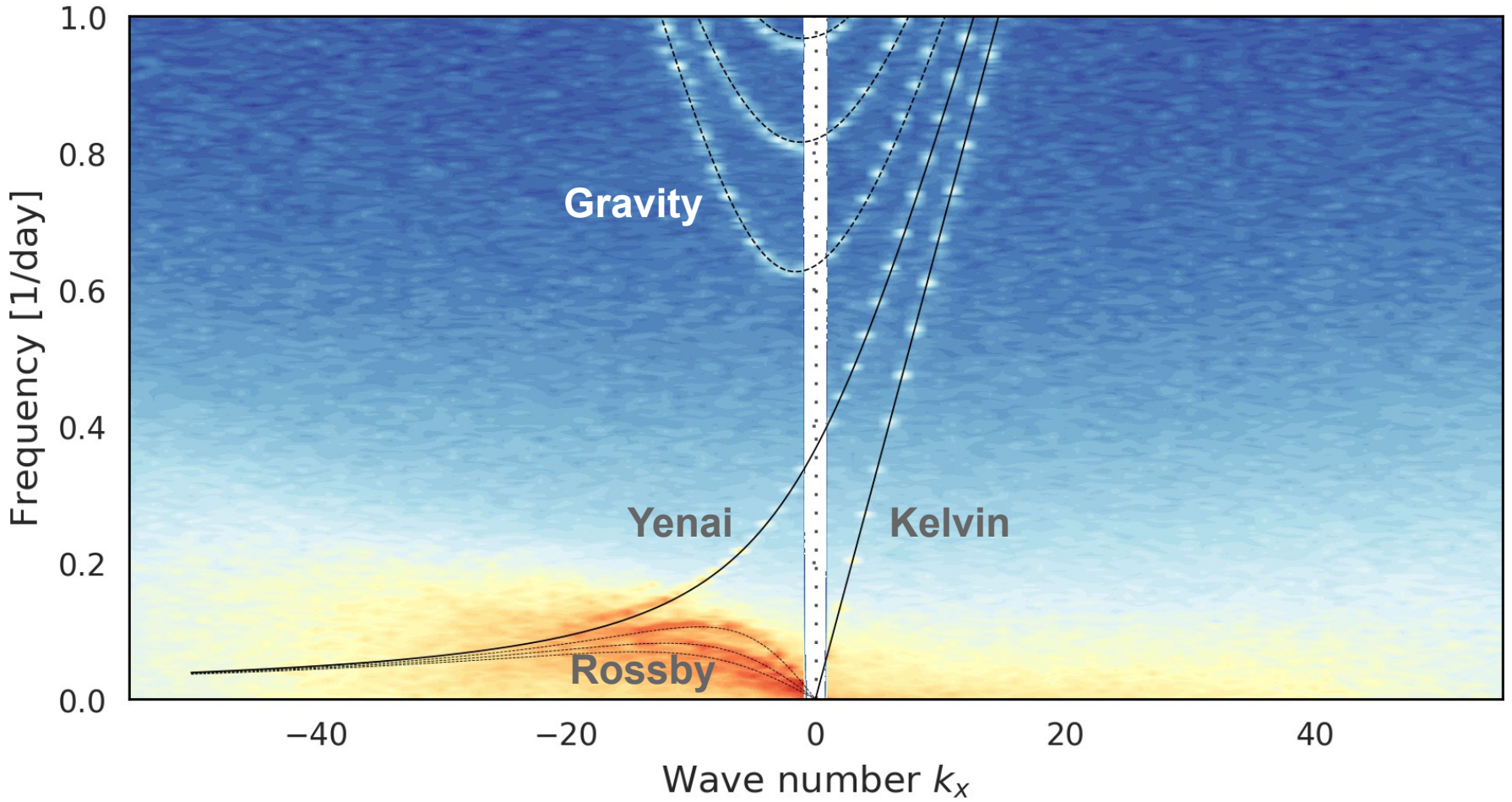


Frisch & Sulem (1984)



… over one magnitude of wave numbers **when forcing vorticity!**

1) Excitation of Equatorial Waves



Equatorial waves follow theoretical dispersion relations in a fully turbulent background.

Schröttle, J., Suhas, D. L., Harnik, N., Sukhatme, J.: 'Turbulence and equatorial waves in moist and dry shallow-water flow, excited through mesoscale stochastic forcing', QJRMS, 2021 doi: 10.1002/qj.4220

1) Self-aggregation in a Turbulent Flow

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

Vorticity forced moist shallow water equations

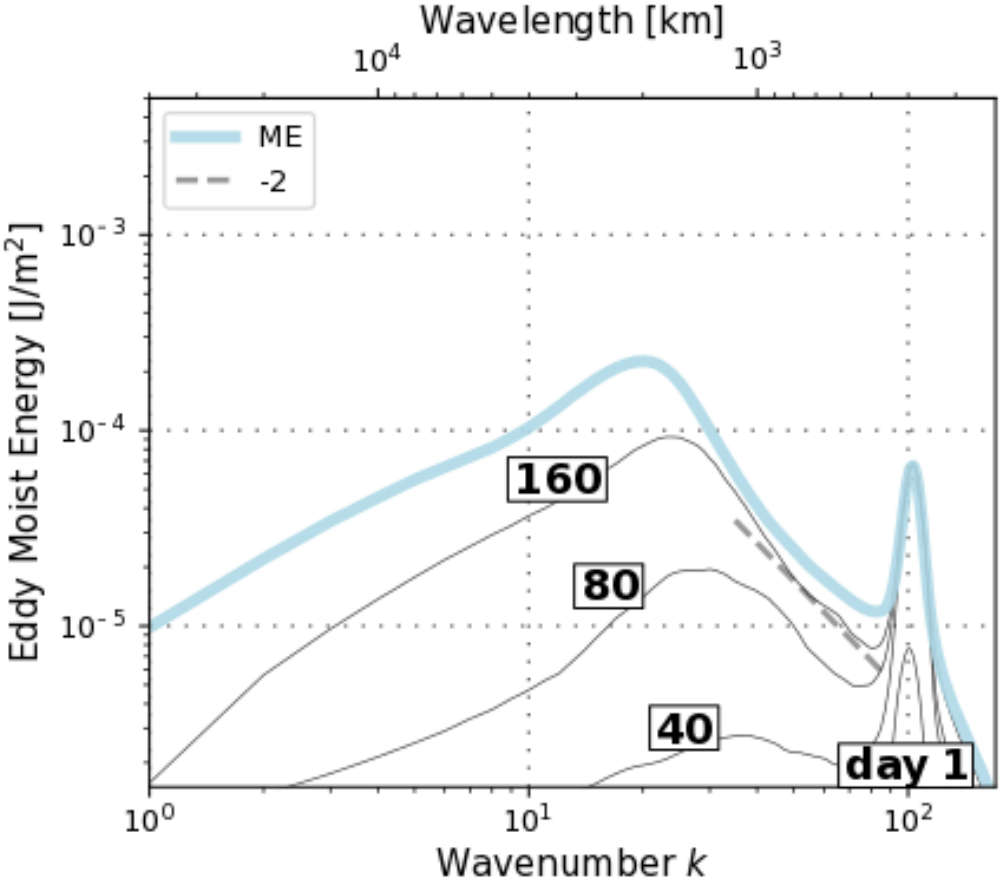
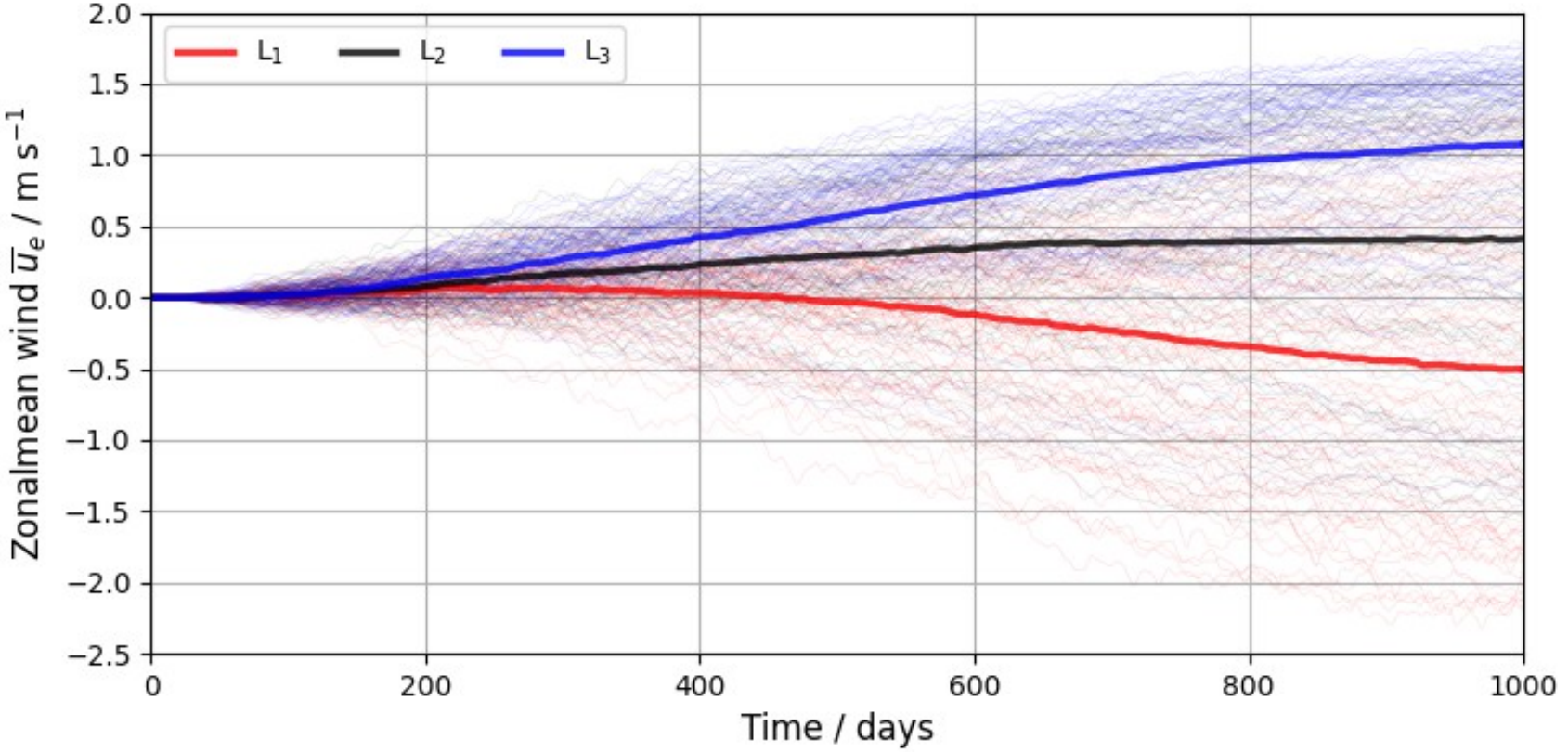


Photo by T. Pesquet, International Space Station, April 25th 2021

Moisture aggregates in fully developed turbulence.

2) Super-rotation in Moist Turbulence

Mean Flow *U* evolves in sob-rotating and super-rotating states:



strongly moist

weakly moist

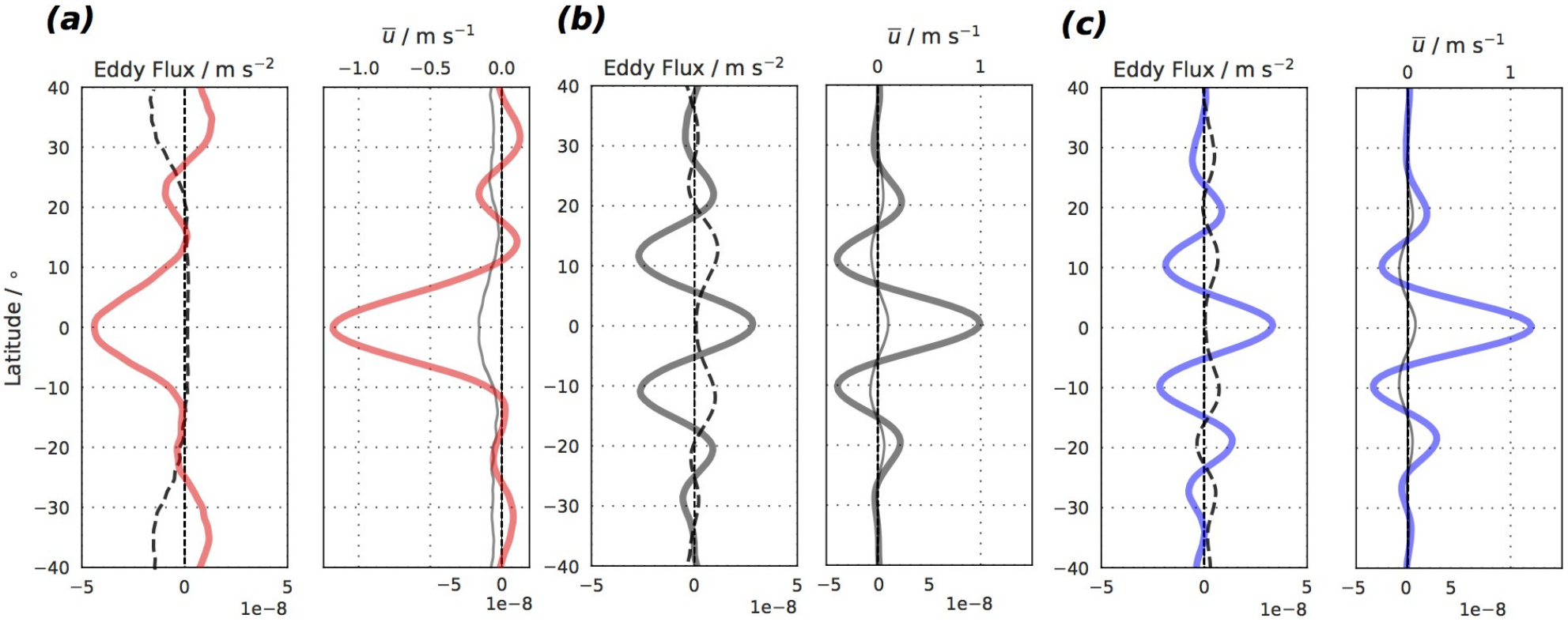
dry

as shown for general circulation models by Suarez & Duffy (1992)

2) Super-rotation in Moist Turbulence

Ensemble statistics of 80 members in each latent heat release group:

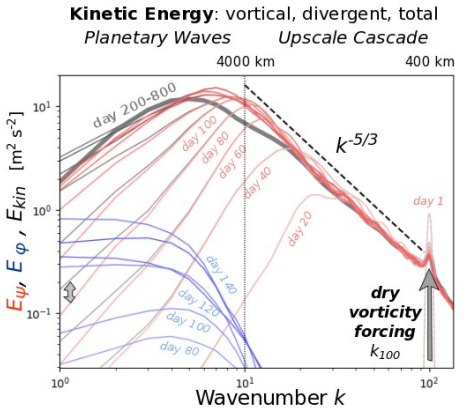
all profiles are averaged over the last 200 days of the simulations



Mean Flow is driven by eddy flux divergence/convergence

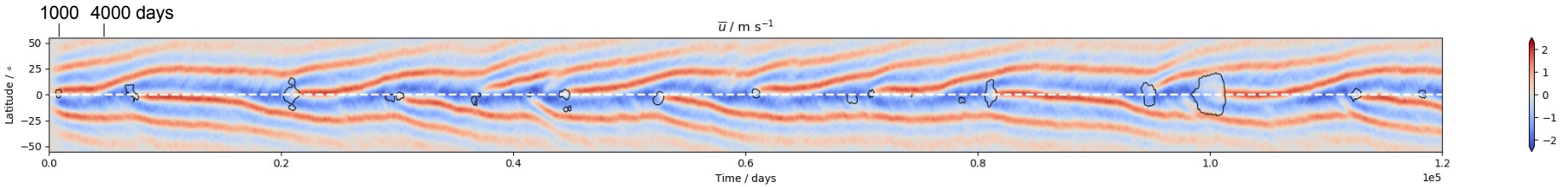
(through interacting planetary, synoptic & mesoscales)

Contributions & Outlook



- We are able to obtain a **turbulent upscale cascade** and internal excitation of theoretical linear waves (Starting from mesoscale noise to 10 000s of km). We have a moist model as well. This constitutes a new perspective on **moist-convection aggregation** due to a turbulent upscale cascade & embedded excitation of **linear equatorial wave modes**. *(QJ, 21)*

- Speaking about **moisture** - one really interesting result are different mean flows depending on **diabatic heating**: **Forcing vorticity** in a moist environment with latent heat release favors westerlies. Up to a certain threshold, spontaneous transition may occur between super-rotation (westerlies) and easterlies, indicating the existence of **multiple equilibria** In 120,000 day runs *(EGU – Nonlin. & Stoch Dyn., 22).*



idea: Look at northward/southward propagation of jets *(Sheshadri & Plumb, 2017).*

- Next step: Stochastic forcing in multi-layer flow on a **tropical planet** to compare **continuous spectra** & **low-frequency** modes – before removing background *(Yang & Ingersoll, 2013),* moisture aggregation, equatorial waves & possible transitions.