

Is the tropical sky white?

Numerical investigations to elucidate the shape of mesoscale vertical velocity spectra

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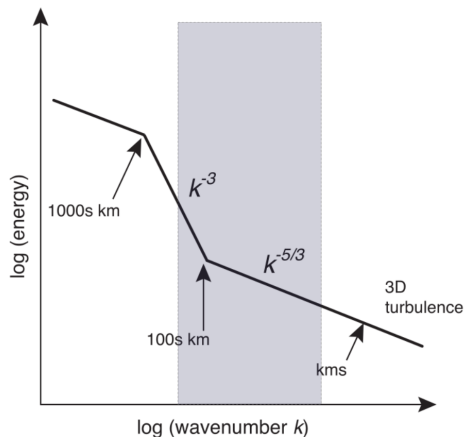
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The atmospheric Kinetic Energy Spectrum has a canonical structure

- Shallow-sloped region at low wavenumbers and global scales
- Steeper-sloped power-law region at intermediate wavenumbers (κ^{-3})
- Mesoscale region with a shallower slope, close to ($\kappa^{-5/3}$)

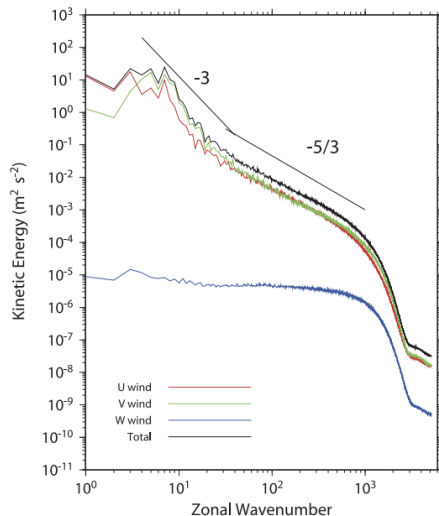
Nastrom and Gage (1985), Lindborg (1999),
Skamarock (2004), Terasaki et. al (2009)



From Skamarock (2014)

What we know from model-derived vertical velocity spectra

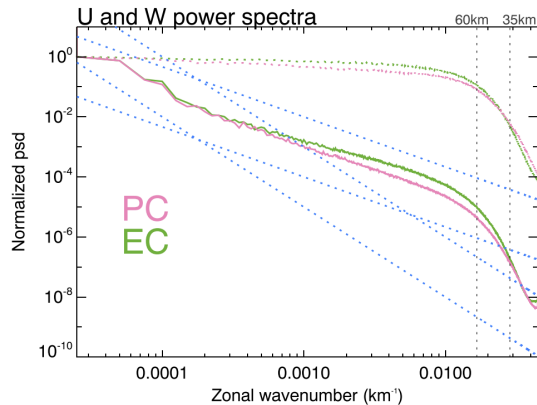
- The vertical velocity possesses much less energy than the horizontal velocity spectra
- The energy spectrum of vertical motion resembles white noise



From Terasaki et. al (2009)

What we know from model-derived vertical velocity spectra

- The vertical velocity possesses much less energy than the horizontal velocity spectra
- The energy spectrum of vertical motion resembles white noise
- The energy spectrum is sensitive to the representation of moist convection.

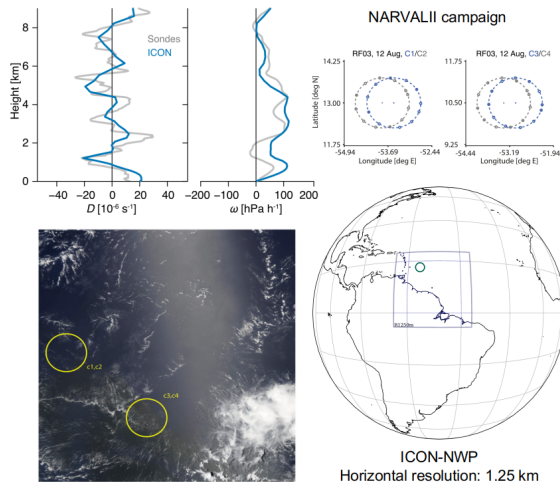


From Stephan et. al (2019)

*EC: explicit convection, PC: parameterized convection

Can we trust model-derived spectra?

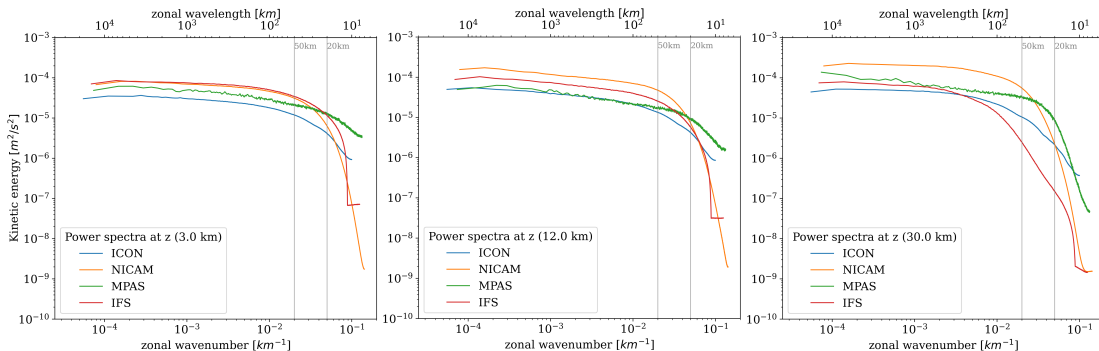
- Lack of vertical velocity measurements with sufficient spatial coverage
- ICON reproduces the spatio-temporal variability of mesoscale horizontal divergence



From Bony, S. & Stevens, B. (2019)

How flat are the vertical velocity spectra?

Global kilometer-scale simulations of several atmospheric models show that vertical velocity spectra are relatively flat on most horizontal scales. The mechanisms that cause this dynamic scaling of vertical velocity remain unknown



Dynamical origin of the vertical energy spectra: Large scales

The vertical velocity spectra links to horizontal kinetic energy by mass continuity at scales $O(>100 \text{ km})$

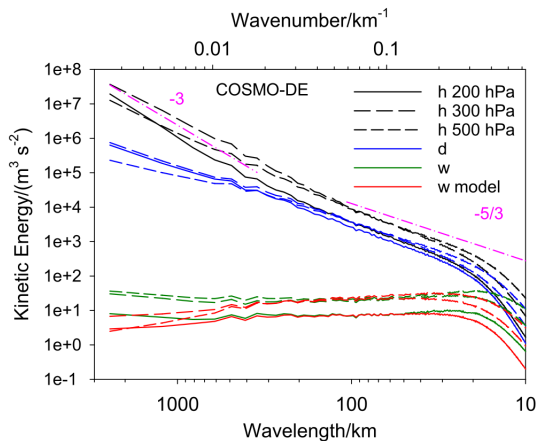
$$\hat{w}\hat{w}^* = h^2 \left[k_x^2 \hat{u}\hat{u}^* + k_x k_y \left(\hat{u}\hat{v}^* + \hat{v}\hat{u}^* \right) + k_y^2 \hat{v}\hat{v}^* \right]$$

Neglecting cross-correlation terms (horizontal isotropy)

$$E_w(k, h) = h^2 k^2 E_D(k, h)$$

Scaling arguments break for large κ and low altitudes: Energy transfer from horizontal to vertical motion is scale dependent

¹U. Schumann (2019)



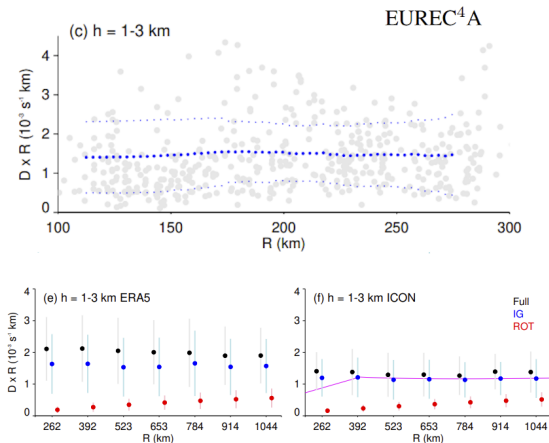
Links between divergence amplitudes and GW spectra: Small scales

Observed area-averaged divergence amplitudes scales inversely with area equivalent radius

$$\text{Div} \sim (kA_x + lA_y) \cos(kx + ly + mz - \omega t + \phi)$$

$$A_D(k^*) \sim \sum_{k=1}^{k=k^*} k \cdot A_x(k) \sim \sum_{k=1}^{k=k^*} k \cdot k^{\sigma(k)},$$

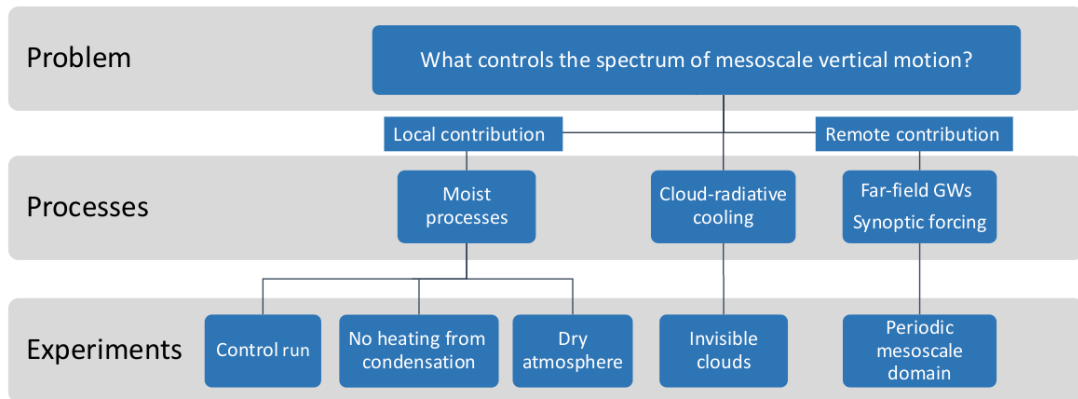
The spectra of Inertia Gravity Waves can explain the scaling of divergence amplitudes with area



²Stephan and Mariaccia (2020)

Mechanistic approach

We perform mechanism denial experiments in a limited area domain using ICON-NWP with spatial resolution of 1.25 km



Numerical experiments



Full moist physics:

- NARVAL2 physics configuration



Dry atmosphere:

- Water categories initialized to zero
- Surface latent heat flux turned off



No heating from condensation:

- Heating rates from condensation do not affect temperature
- Includes surface heat fluxes



Invisible clouds:

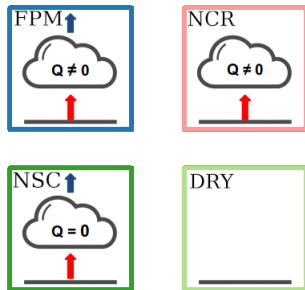
- Clouds have no impact on radiation



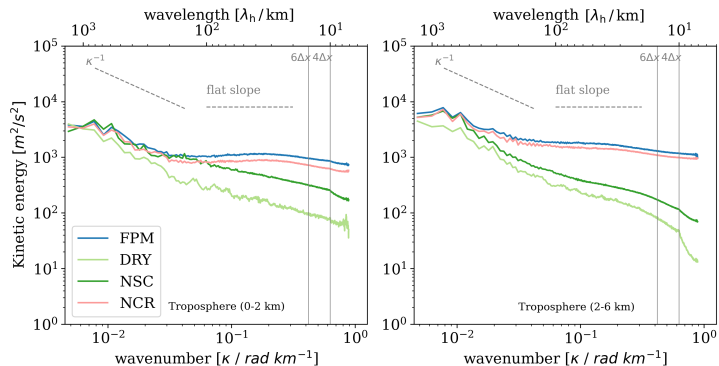
ICON-NWP 48 hour simulation, Aug 12, 2016
Resolution: 1.25 km

Filling the mesoscale spectral gap

Mechanism denial experiments



Vertical velocity spectra computed at 2.5 km resolution

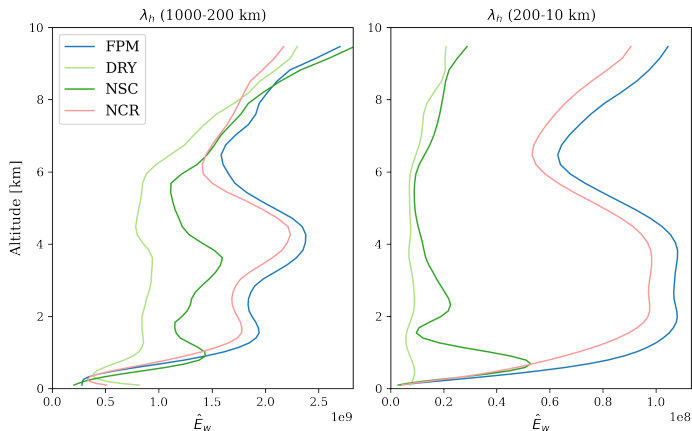


Vertical dependence of the spectra

Mechanism denial experiments

- The spectra in the long wavelength region (1000-200 km) are dominated by external forcing.
- Latent heat release contributes the largest fraction of the spectral energy through the troposphere at scales (< 200 km).

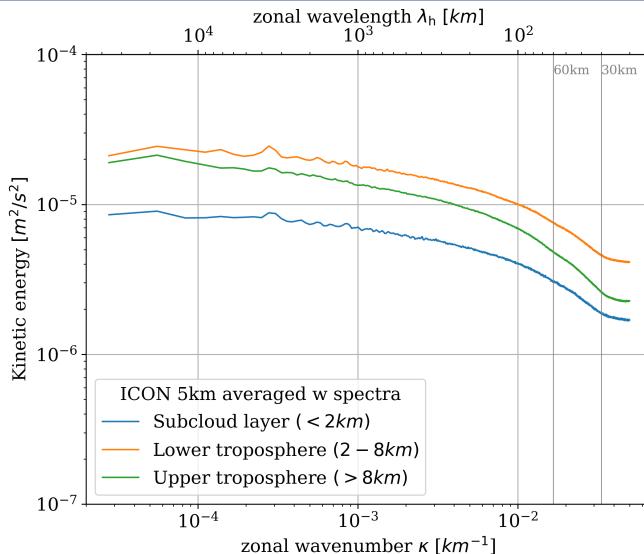
Profiles of integrated vertical velocity spectra



Vertical dependence of the spectra

ICON global simulation with explicit convection at 5 km horizontal resolution

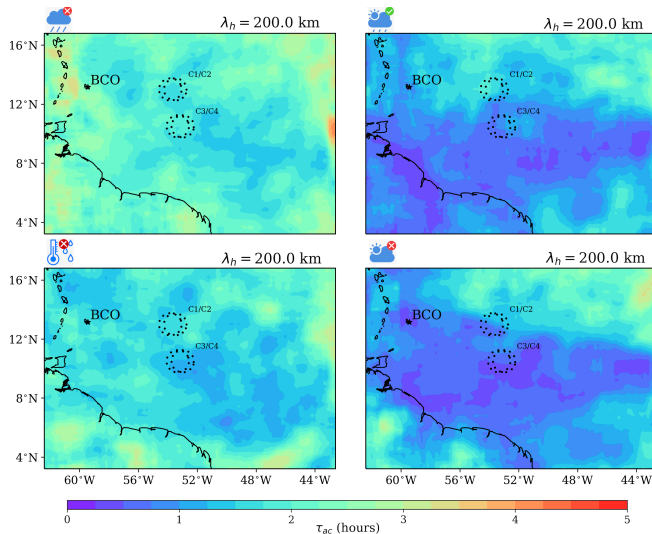
- The maximum power of the vertical kinetic energy spectrum is within the cloud layer (2-8 km)
- Spectral slopes have a weak dependence on height with a slight steepening from the subcloud layer and up to the free troposphere.



Auto-correlation time-scales

Lower troposphere (0-8 km)

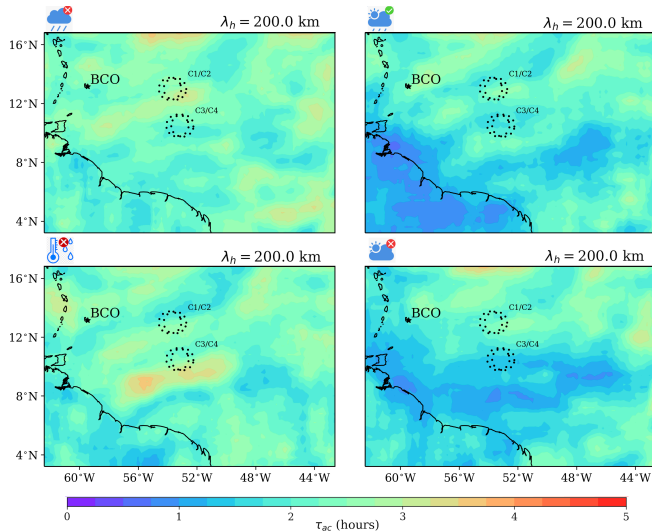
- Moist simulation agrees well with the time-scales found in observations (3 hours)
- Time scales increase when moist processes are excluded
- Latent heating from convection modulate divergence's temporal variability



Auto-correlation time-scales

Upper troposphere (8-16 km)

- Smaller differences among all simulations
- The effects of moist convection on divergence variability are limited to the lower troposphere



Summary and conclusions

- Moist processes have a significant impact on the spatio-temporal scales of variation of divergence.
 - All experiments show a systematic decrease in the temporal autocorrelation inside convective areas
 - Moist convection appears to destroy the temporal coherence of the divergence field.
- Moist convection controls the spectral shape of vertical velocity.
 - Local moist processes contribute the largest fraction to the spectrum ($\lambda_h < 200$ km)
 - The spectral response to moist processes is broad and extends into the free troposphere
 - The spectral signature of buoyancy fluxes instead is confined to $z < 3$ km
 - The DRY experiment shows a power law corresponding to blue noise ($\beta \approx 1$). To reproduce the flatness of the spectra, the inclusion of moist convective processes is required.