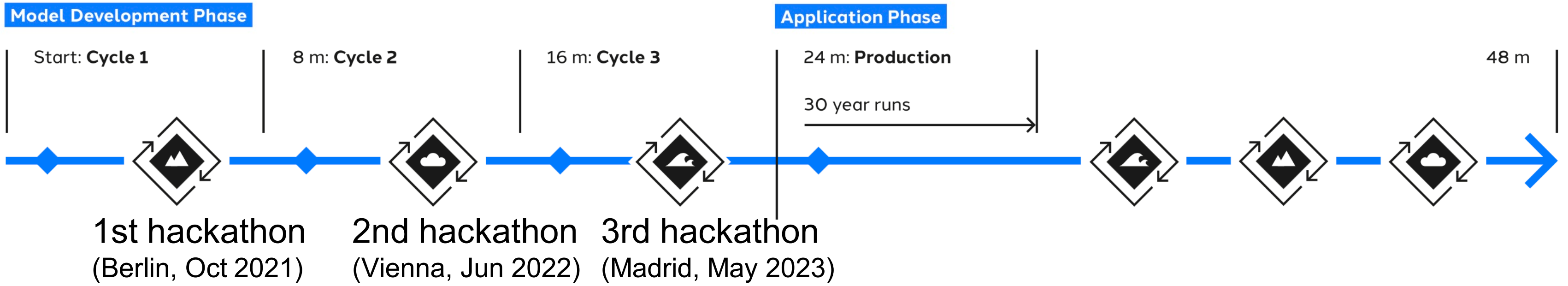
How to represent deep convection at km-scale resolutions?

Tobias Becker

in collaboration with Peter Bechtold, Irina Sandu, Richard Forbes, Thomas Rackow, Xabier Pedruzo and others

Development Cycles in nextGEMS

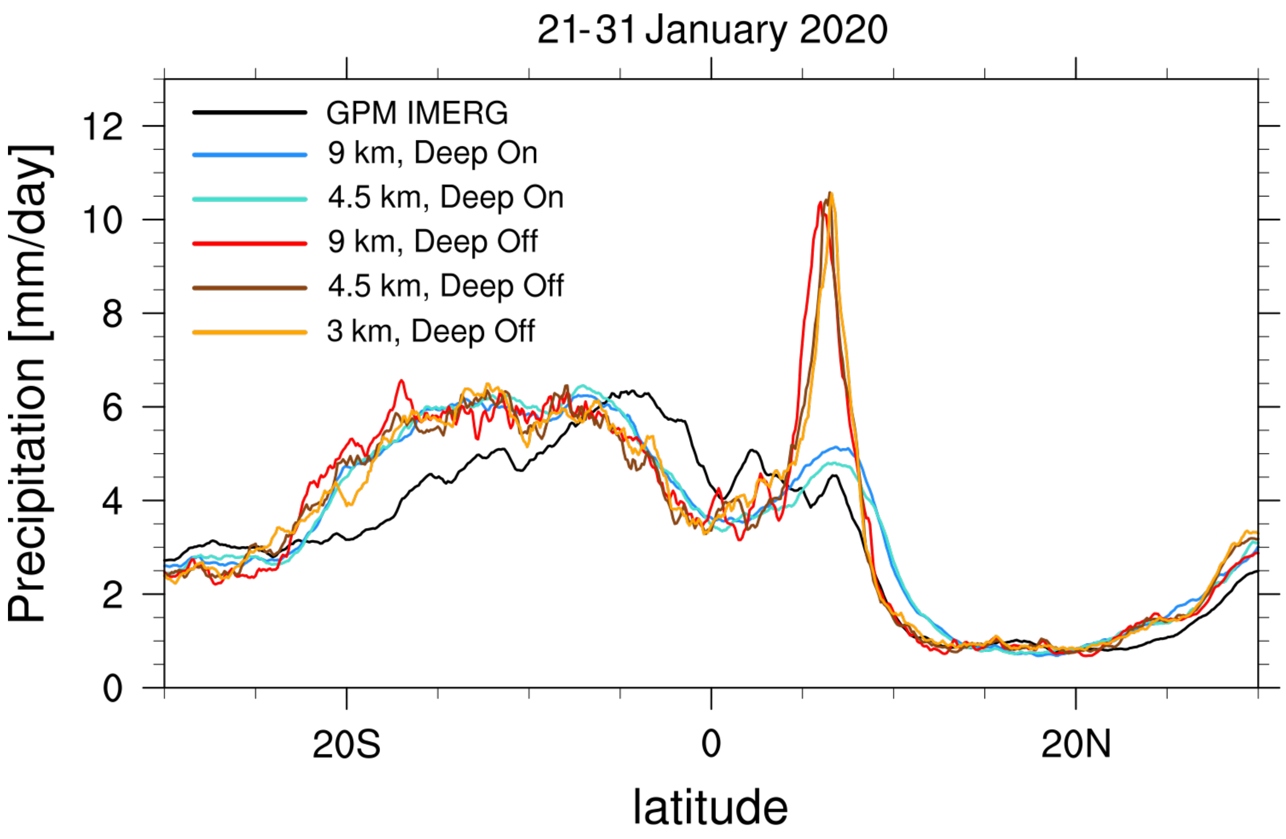


- development cycles with aim to run 30 year coupled simulations at km-scale resolution (4.5 / 3 km)
  - **technical challenges:** new supercomputer environments, coupling IFS to two ocean models (Nemo & Fesom), unprecedented simulation lengths, huge data amounts
  - **scientific challenges:** water and energy conservation, TOA radiation budgets, climate statistics

Wind gusts over Europe (N. Koldunov, AWI)

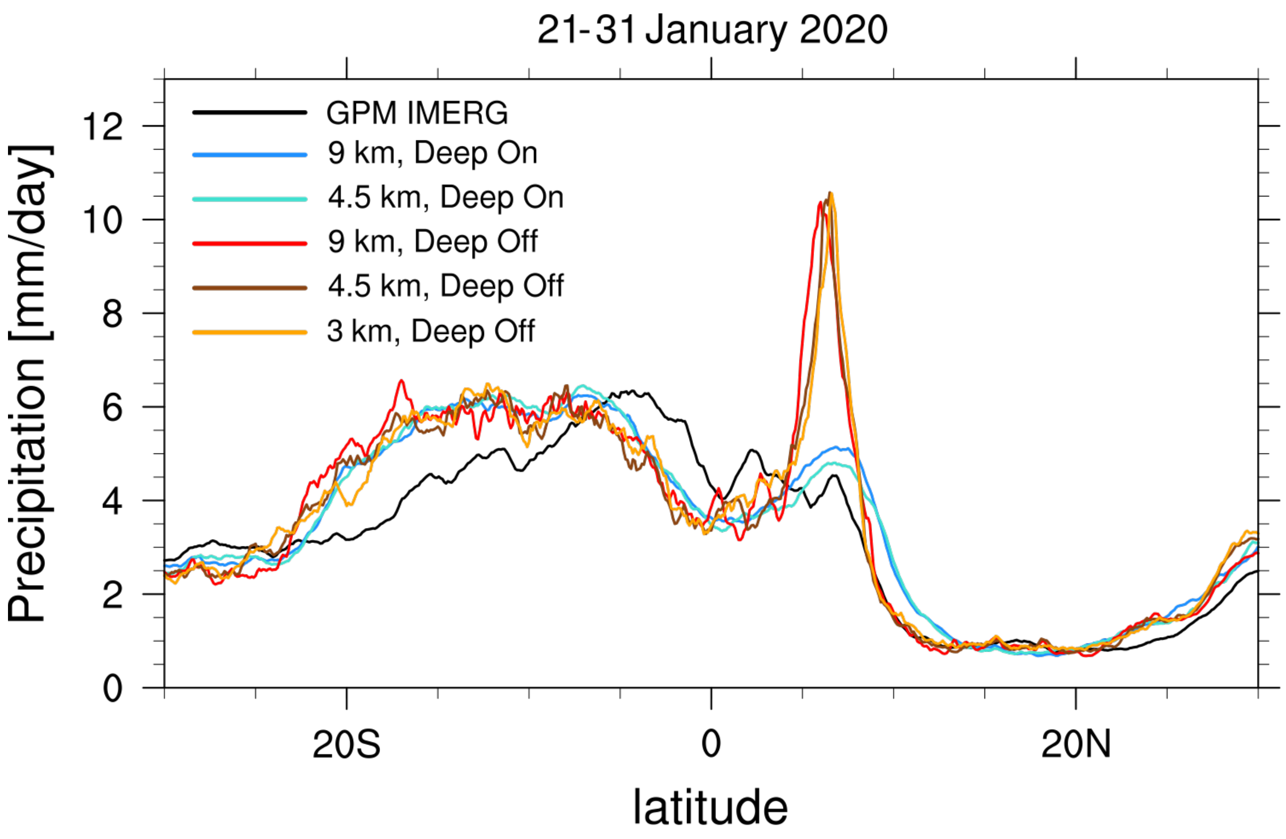
Precipitation statistics in nextGEMS Cycle 2

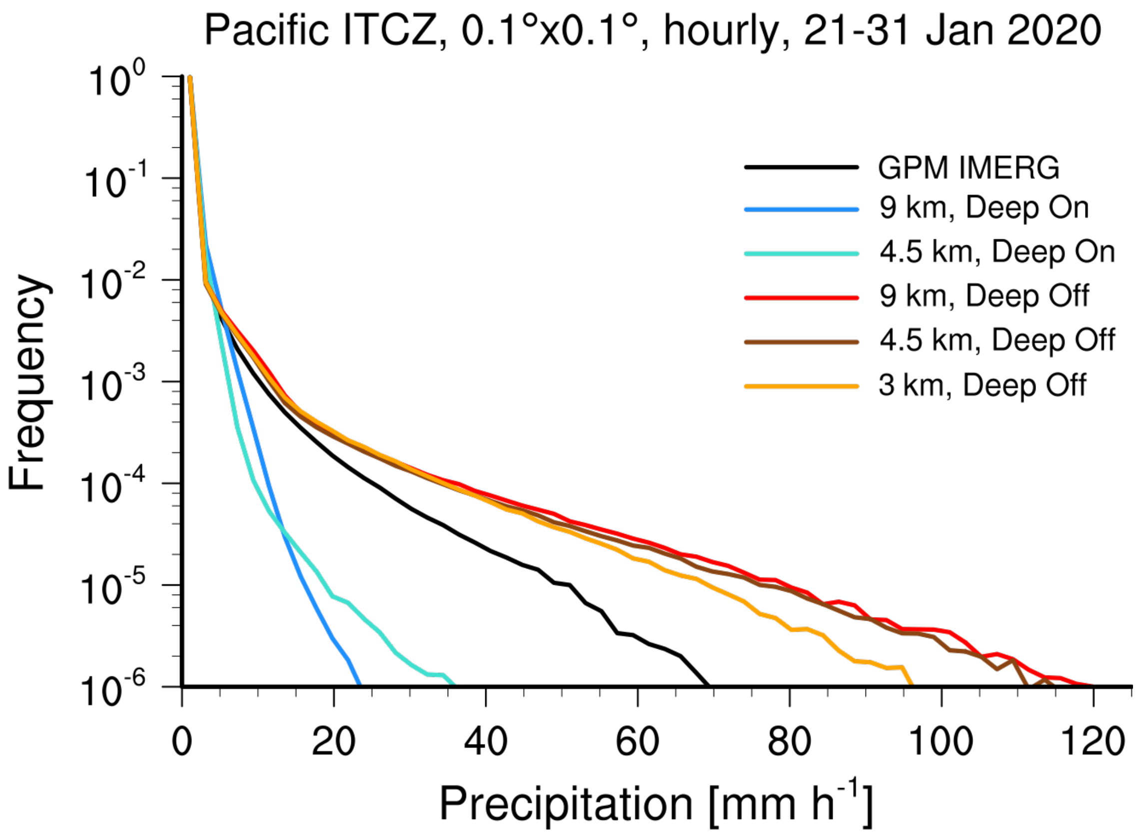
- zonal mean precipitation strongly overestimated over NH Pacific ITCZ with Deep Off



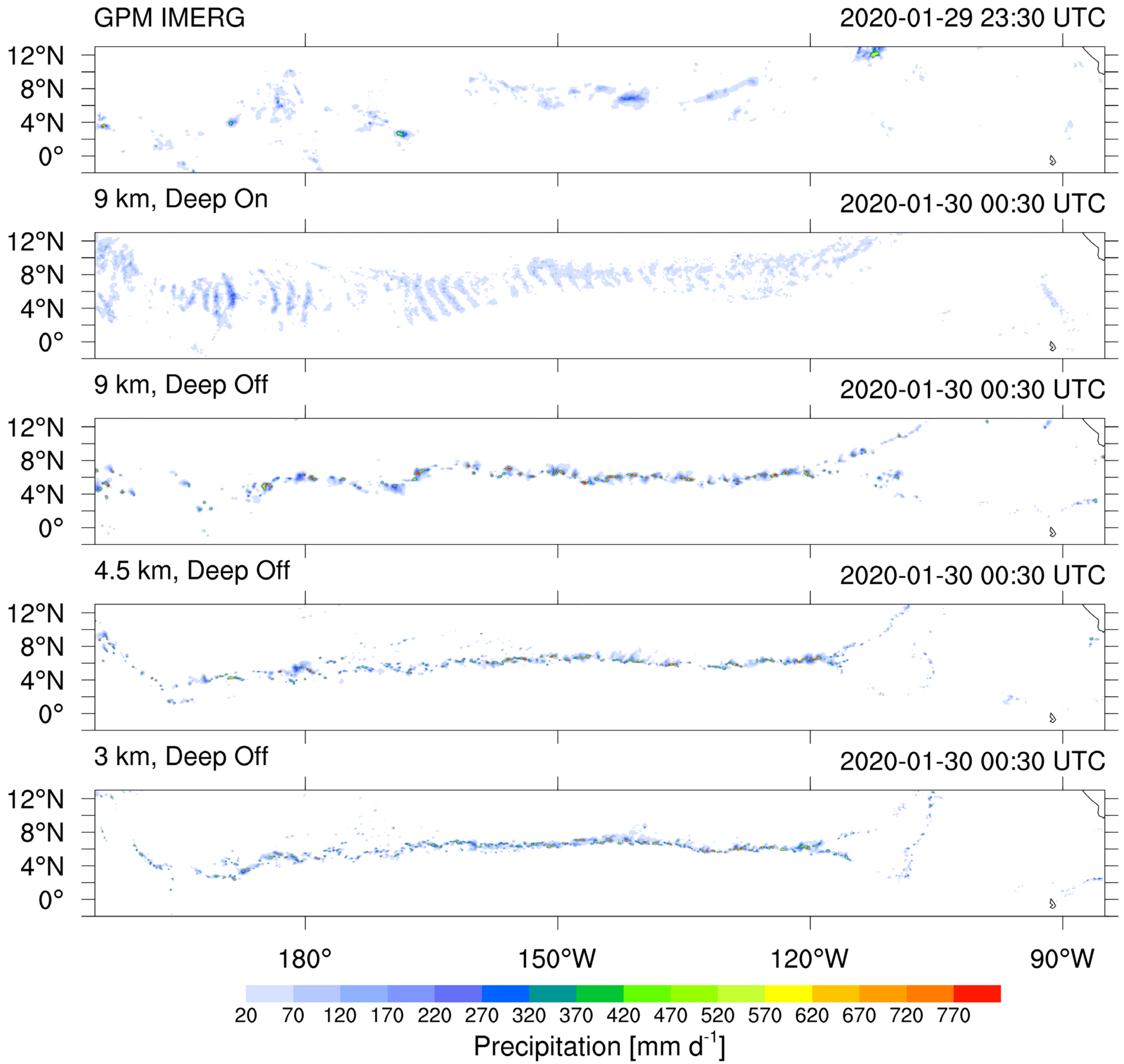
Precipitation statistics in nextGEMS Cycle 2

- zonal mean precipitation strongly overestimated over NH Pacific ITCZ with Deep Off
- precipitation too intense with Deep Off and not intense enough with Deep On





Precipitation over Pacific ITCZ in nextGEMS Cycle 2



- wave solution dominates with Deep On
- strong line of convergence with Deep Off (independent of resolution)

Sensitivity study

What are possible problems? (at 1-9 km resolution)

- some parameters in microphysics assume that convection occurs only in part of grid cell
- horizontal mixing between updraft and environment not resolved
- processes that trigger deep convection not resolved

Sensitivity study

What are possible problems? (at 1-9 km resolution) How can we test/improve them?

- some parameters in microphysics assume that convection occurs only in part of grid cell
  ➔ increase relative humidity threshold for evaporation of hydrometeors from 0.8 to 1
- horizontal mixing between updraft and environment not resolved
- processes that trigger deep convection not resolved

Sensitivity study

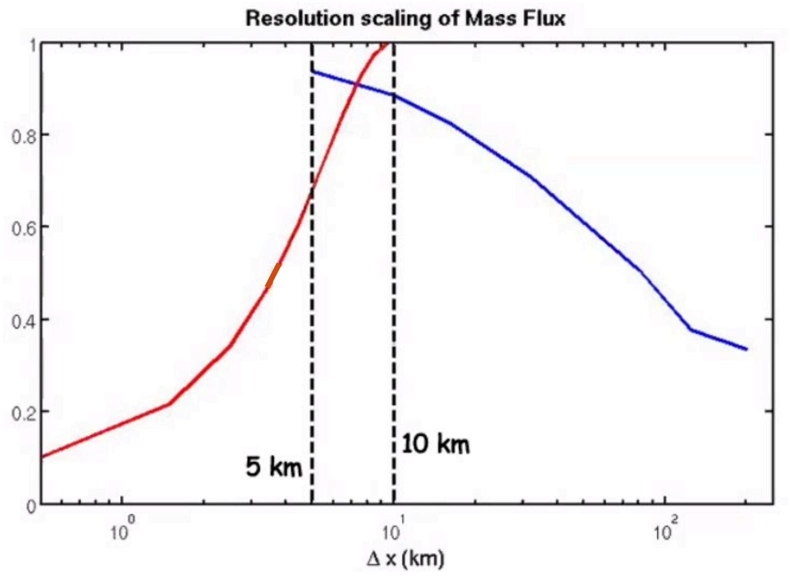
What are possible problems? (at 1-9 km resolution) How can we test/improve them?

- some parameters in microphysics assume that convection occurs only in part of grid cell
  ➔ increase relative humidity threshold for evaporation of hydrometeors from 0.8 to 1
- horizontal mixing between updraft and environment not resolved
  ➔ increase spectral diffusion by a factor of 100
- processes that trigger deep convection not resolved

Sensitivity study

What are possible problems? (at 1-9 km resolution) How can we test/improve them?

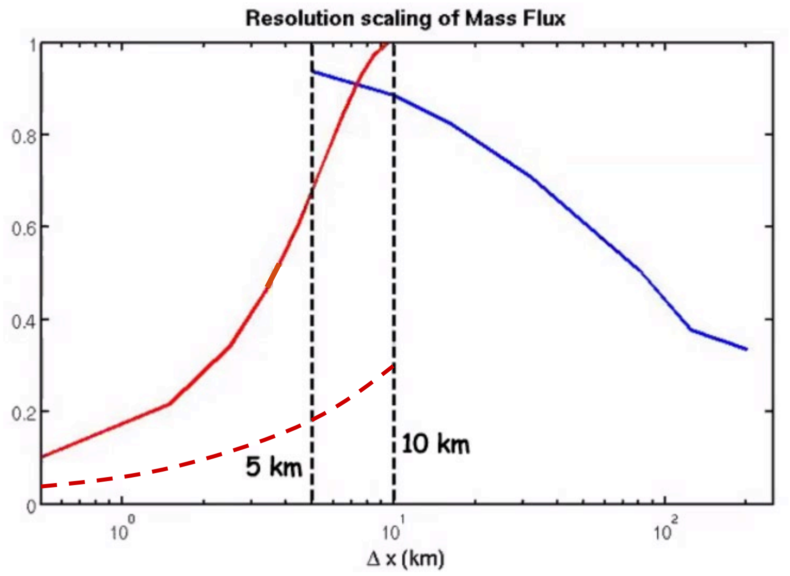
- some parameters in microphysics assume that convection occurs only in part of grid cell
  ➔ increase relative humidity threshold for evaporation of hydrometeors from 0.8 to 1
- horizontal mixing between updraft and environment not resolved
  ➔ increase spectral diffusion by a factor of 100
- processes that trigger deep convection not resolved
  ➔ keep deep convection a little bit active with strongly reduced cloud base mass flux



Sensitivity study

What are possible problems? (at 1-9 km resolution) How can we test/improve them?

- some parameters in microphysics assume that convection occurs only in part of grid cell
  ➔ increase relative humidity threshold for evaporation of hydrometeors from 0.8 to 1
- horizontal mixing between updraft and environment not resolved
  ➔ increase spectral diffusion by a factor of 100
- processes that trigger deep convection not resolved
  ➔ keep deep convection a little bit active with strongly reduced cloud base mass flux

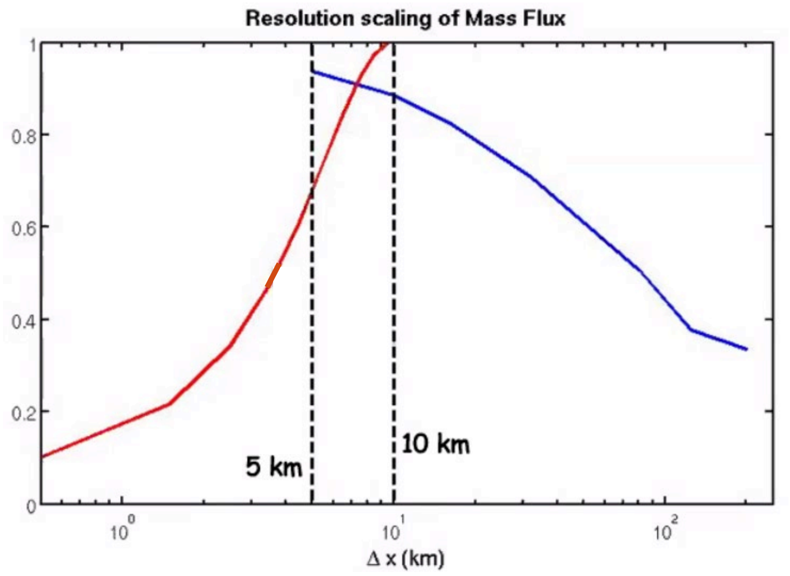


Sensitivity study

What are possible problems? (at 1-9 km resolution) How can we test/improve them?

- some parameters in microphysics assume that convection occurs only in part of grid cell
  ➔ increase relative humidity threshold for evaporation of hydrometeors from 0.8 to 1
- horizontal mixing between updraft and environment not resolved
  ➔ increase spectral diffusion by a factor of 100
- processes that trigger deep convection not resolved
  ➔ keep deep convection a little bit active with strongly reduced cloud base mass flux

  ➔ handle hydrometeors explicitly by detraining 30% to the microphysics



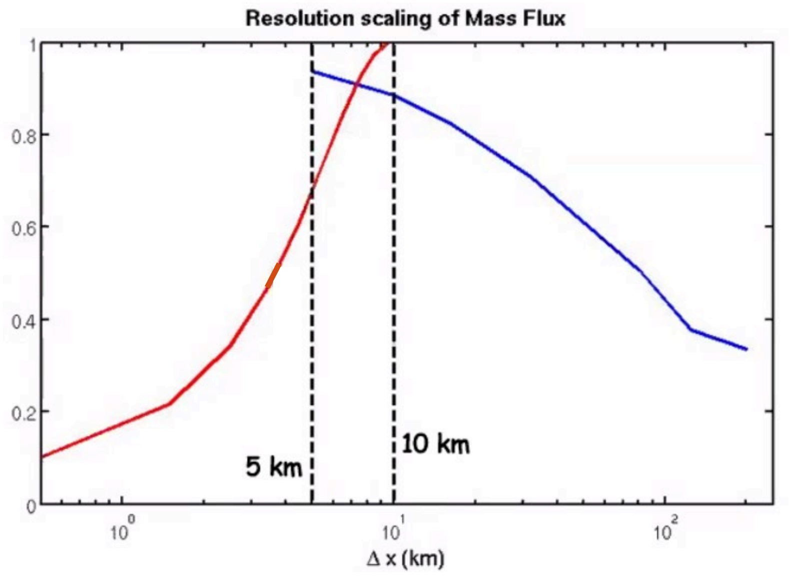
Sensitivity study

What are possible problems? (at 1-9 km resolution) How can we test/improve them?

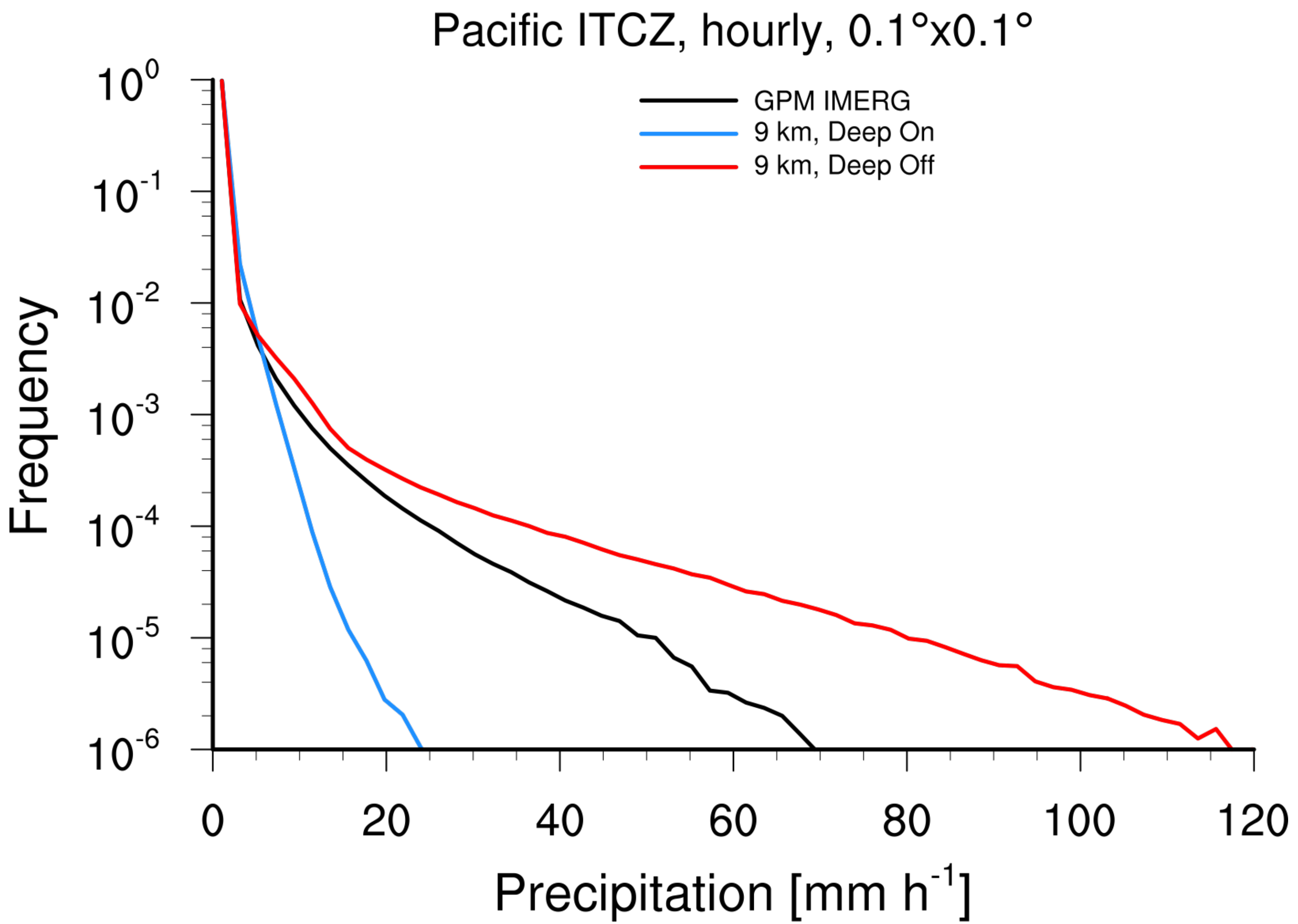
- some parameters in microphysics assume that convection occurs only in part of grid cell
  ➔ increase relative humidity threshold for evaporation of hydrometeors from 0.8 to 1
- horizontal mixing between updraft and environment not resolved
  ➔ increase spectral diffusion by a factor of 100
- processes that trigger deep convection not resolved
  ➔ keep deep convection a little bit active with strongly reduced cloud base mass flux

  ➔ handle hydrometeors explicitly by detraining 30% to the microphysics

- 12 day simulations at 9 km resolution, started on Jan 20, 2020 (as nextGEMS)

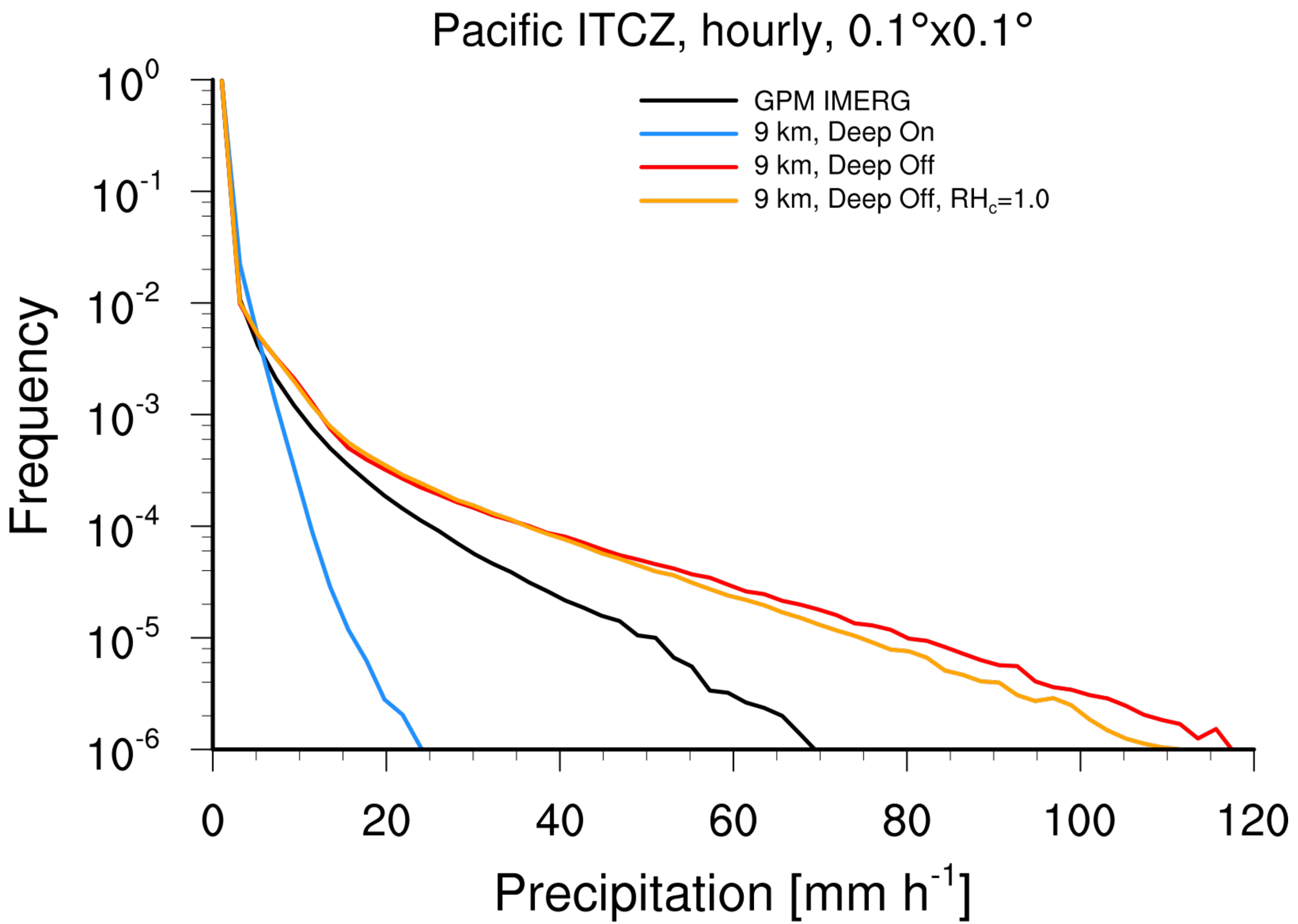


Precipitation intensity



- precipitation intensity is overestimated with Deep Off and underestimated with Deep On

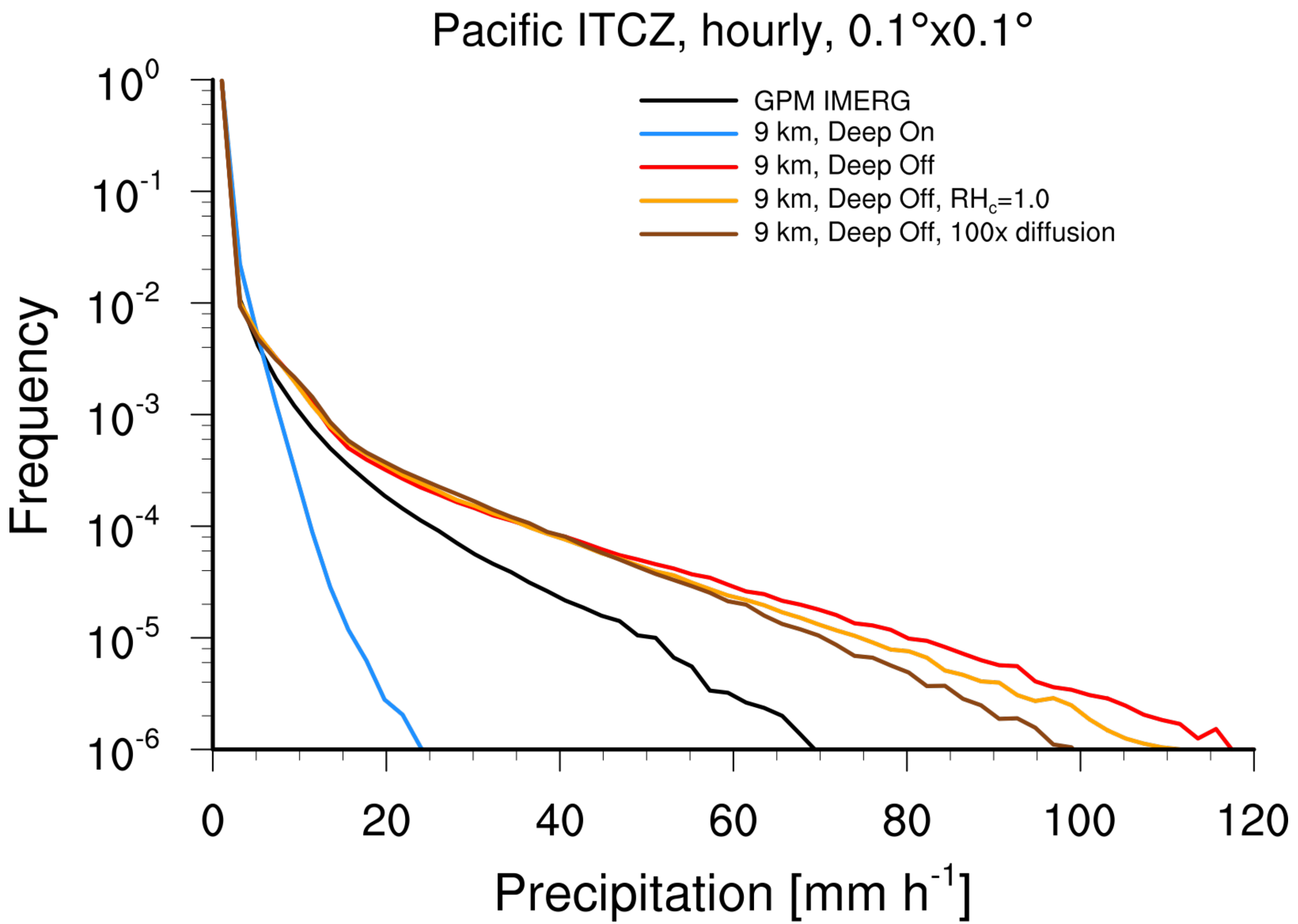
Precipitation intensity



- precipitation intensity is overestimated with Deep Off and underestimated with Deep On
- change assumption in micro-physics gives small improvement

ECMWF

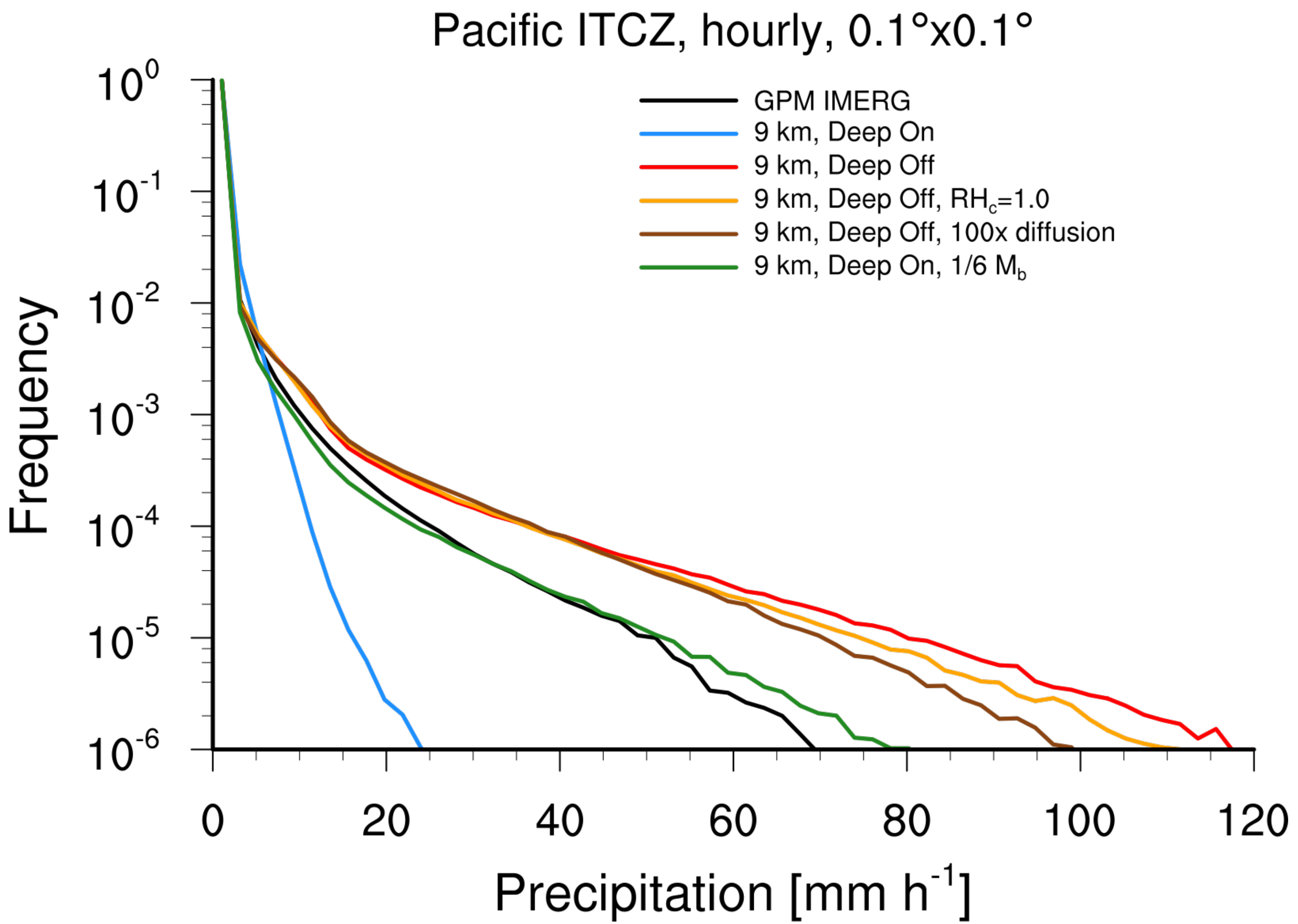
Precipitation intensity



- precipitation intensity is overestimated with Deep Off and underestimated with Deep On
- change assumption in micro-physics gives small improvement
- 100x more diffusion reduces precipitation intensity

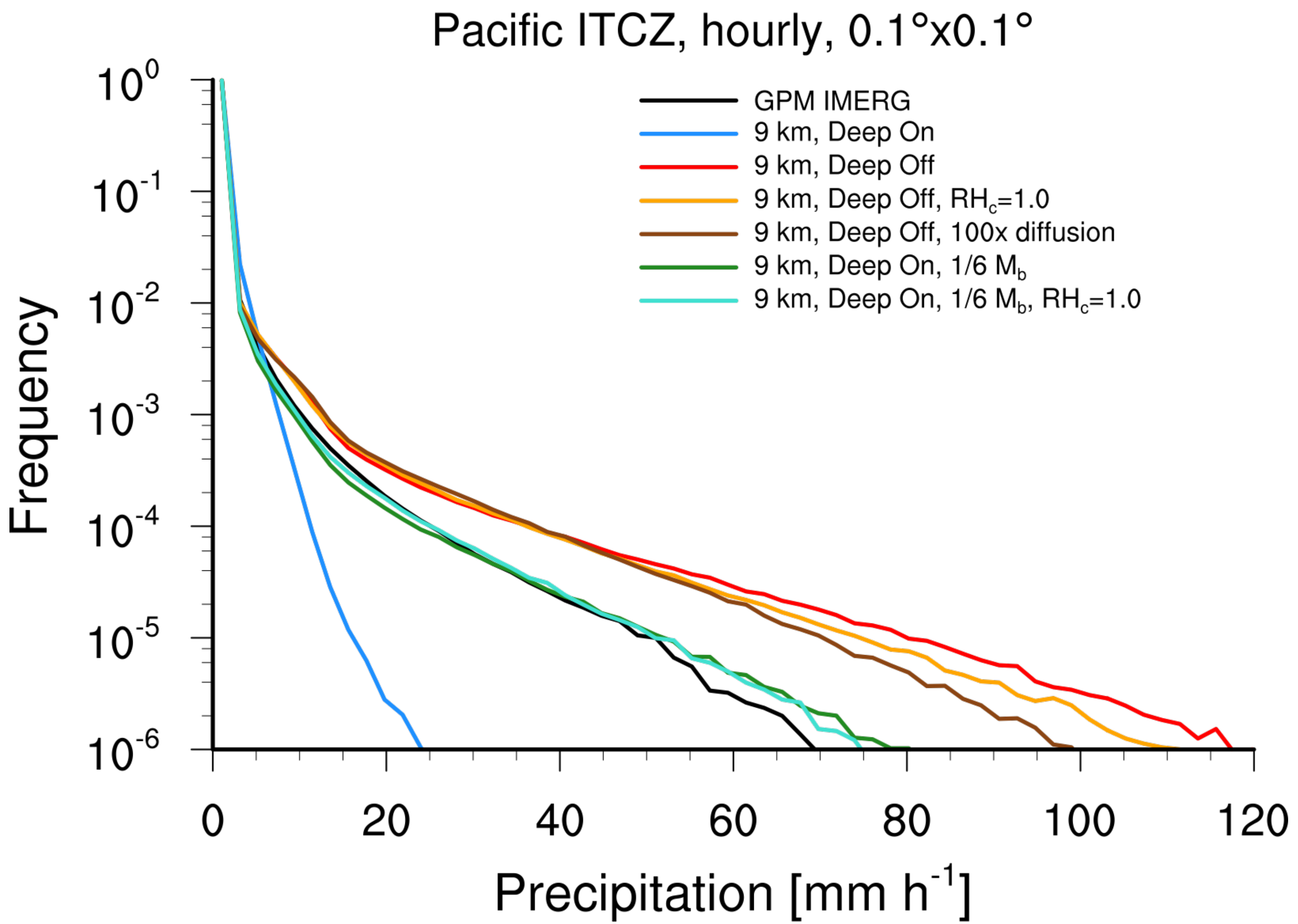
ECMWF

Precipitation intensity



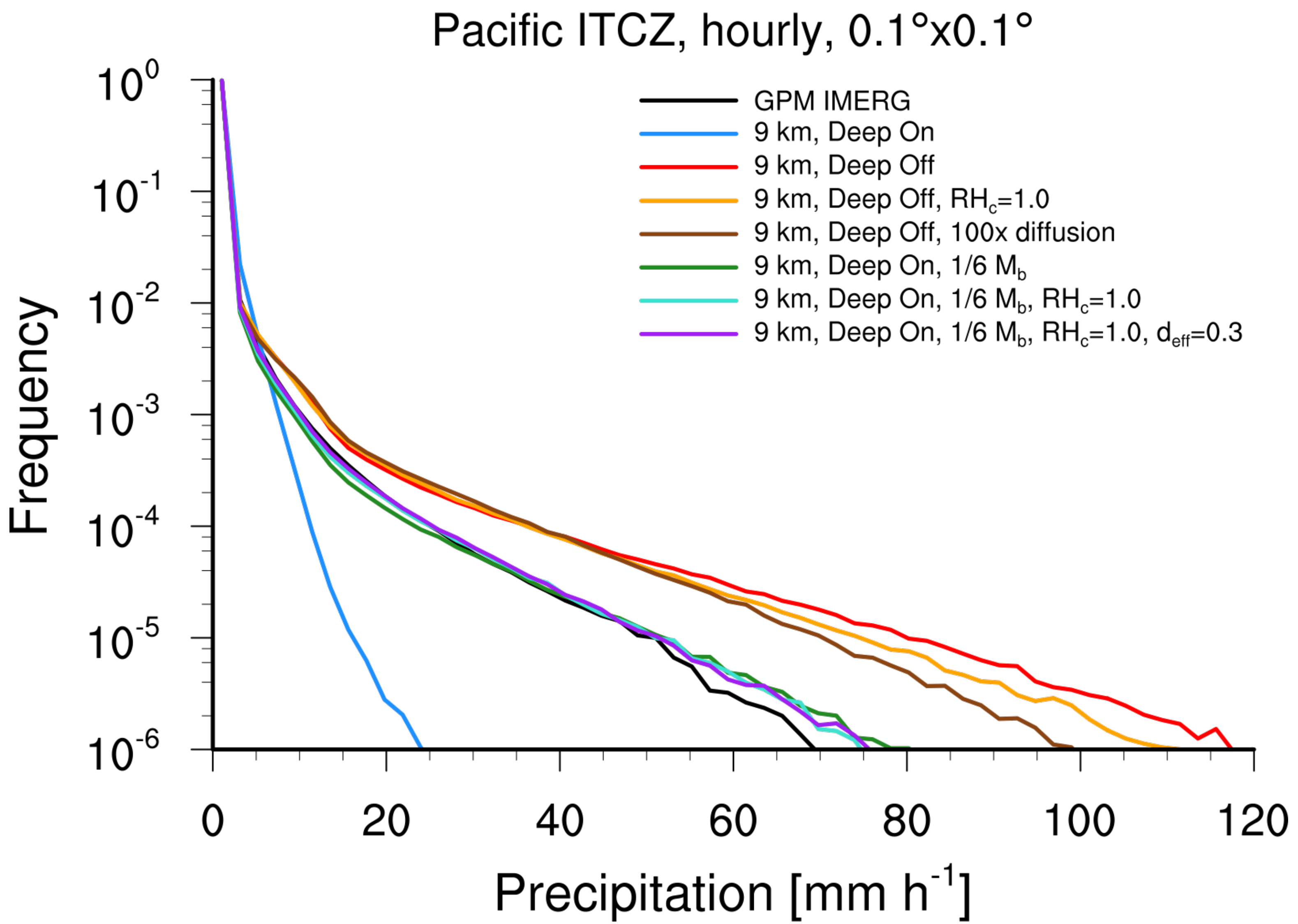
- precipitation intensity is overestimated with Deep Off and underestimated with Deep On
- change assumption in micro-physics gives small improvement
- 100x more diffusion reduces precipitation intensity
- slightly active d.c. scheme gives substantial improvement

Precipitation intensity



- precipitation intensity is overestimated with Deep Off and underestimated with Deep On
- change assumption in micro-physics gives small improvement
- 100x more diffusion reduces precipitation intensity
- slightly active d.c. scheme gives substantial improvement
- add RH_c=1.0 improves precipitation distribution for lower intensities

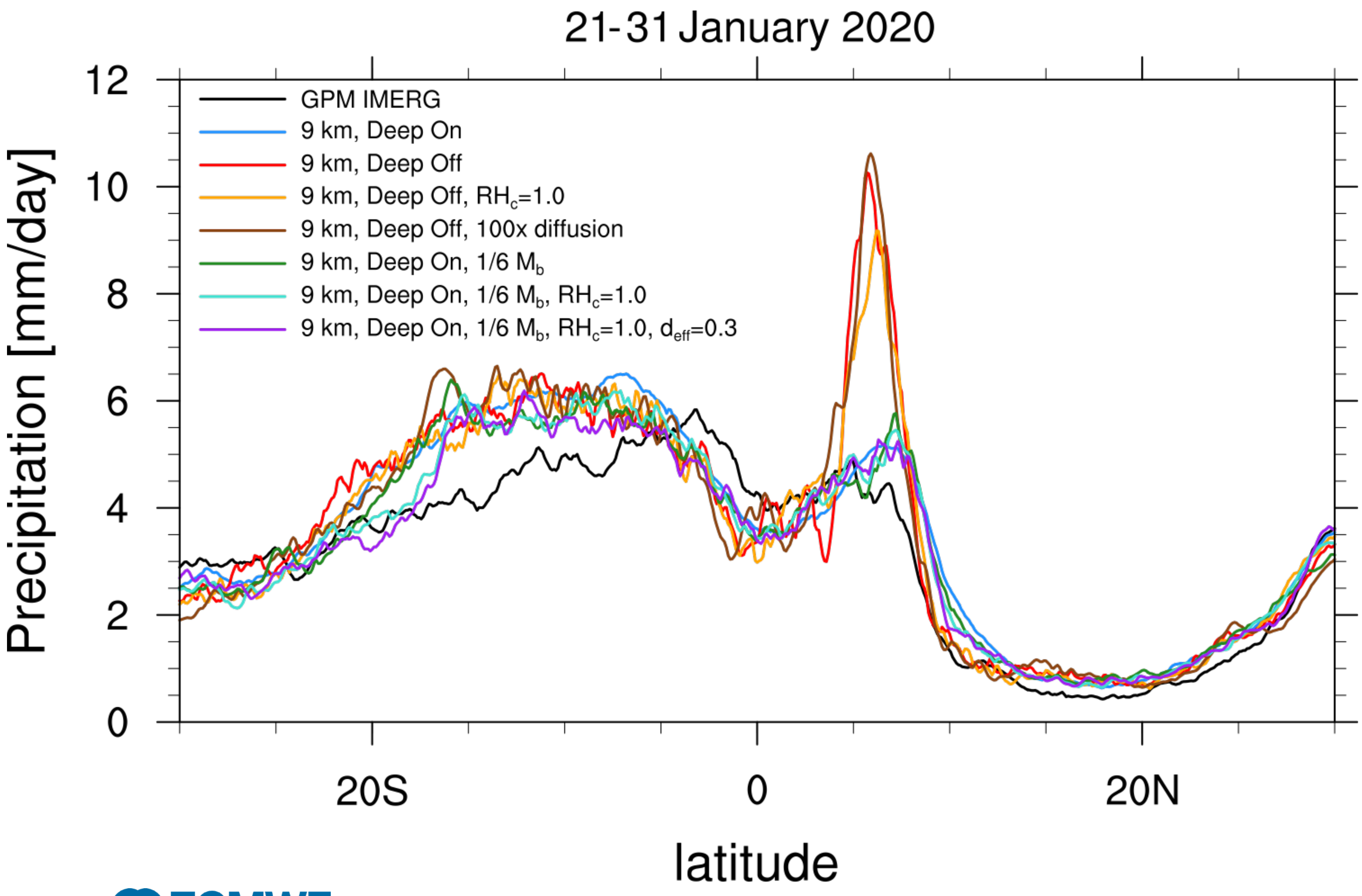
Precipitation intensity



- precipitation intensity is overestimated with Deep Off and underestimated with Deep On
- change assumption in micro-physics gives small improvement
- 100x more diffusion reduces precipitation intensity
- slightly active d.c. scheme gives substantial improvement
- add RH_c=1.0 improves precipitation distribution for lower intensities
- similar with increased detrainment of hydrometeors

ECMWF

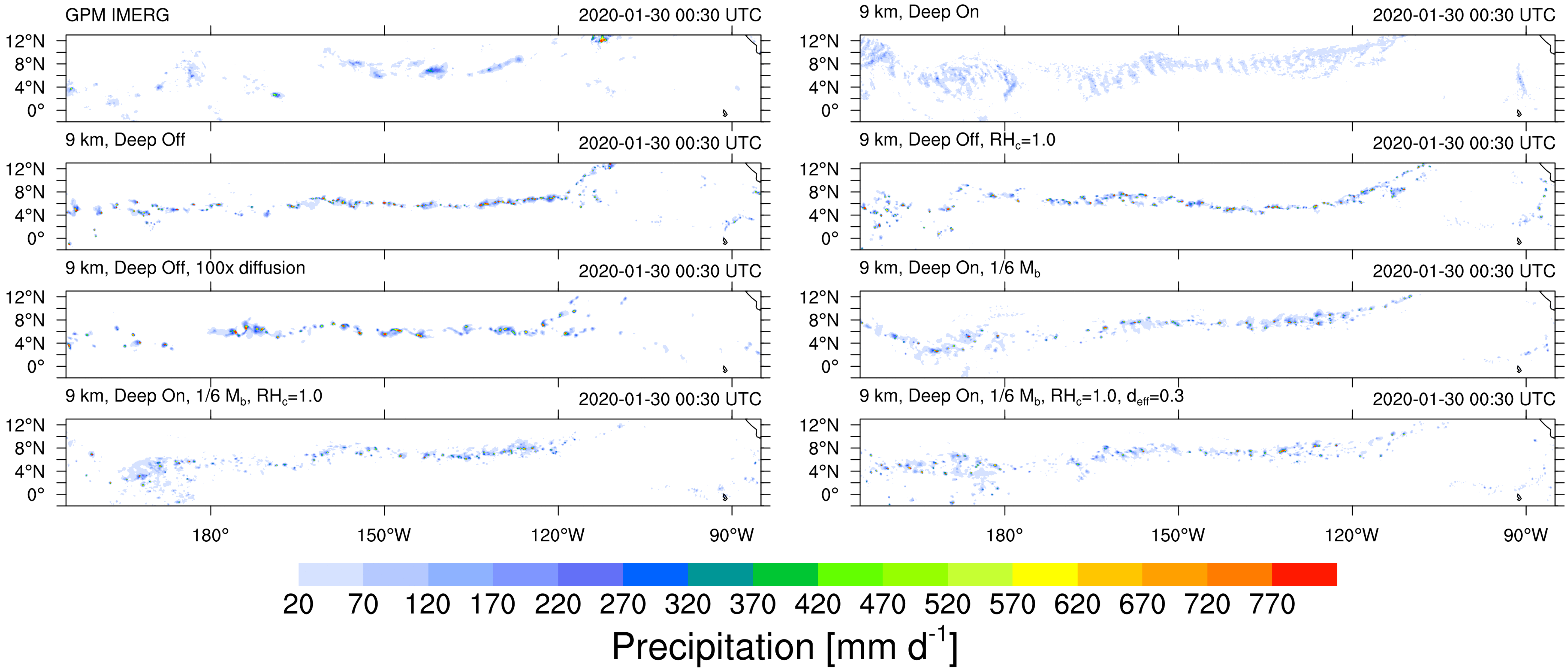
Zonal mean precipitation



- no large bias at 5°N when deep conv. scheme slightly active
- improvements in SH tropics when deep conv. scheme slightly active and RH_c=1.0

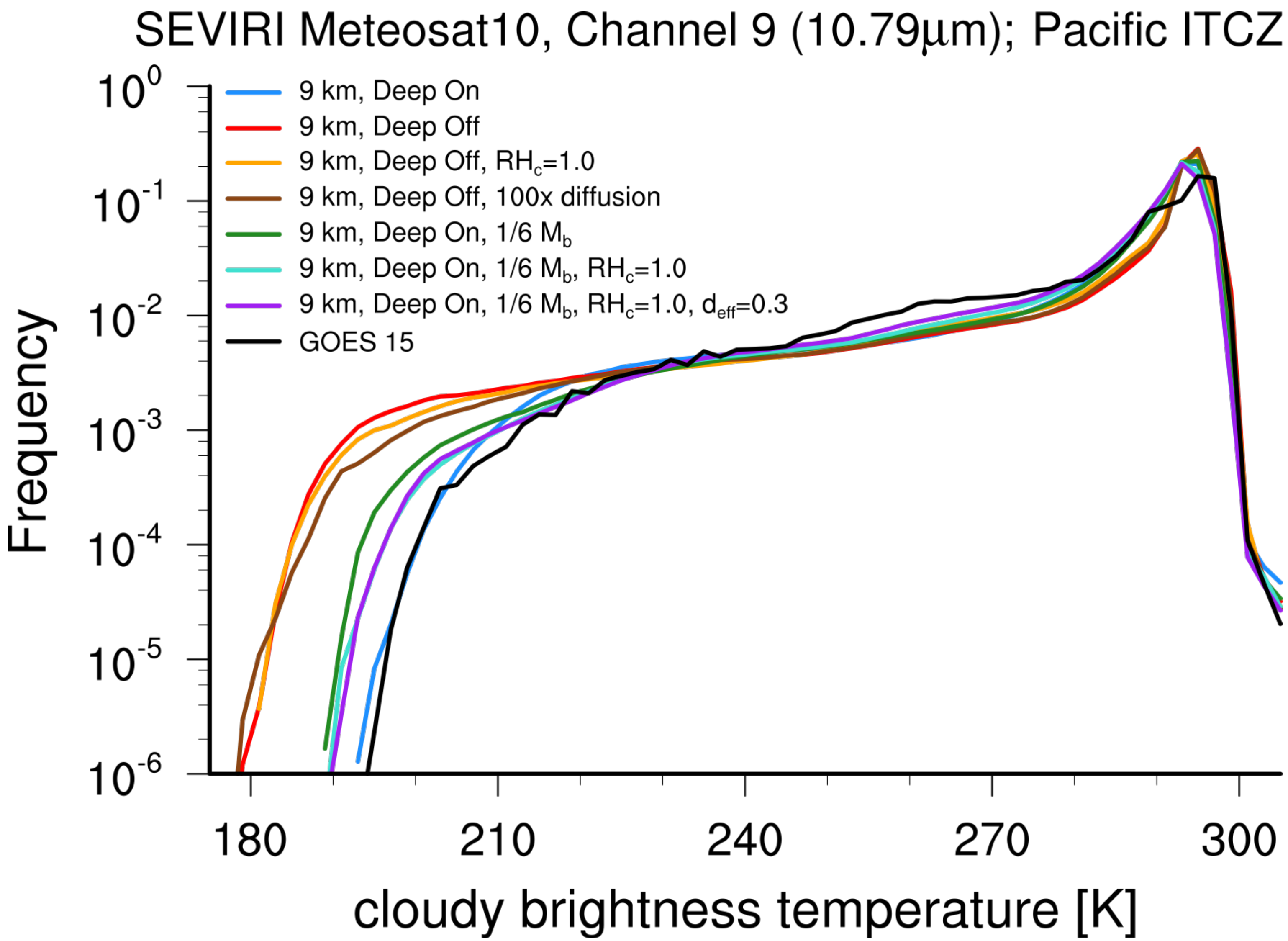
ECMWF

Precipitation over Pacific ITCZ



ECMWF

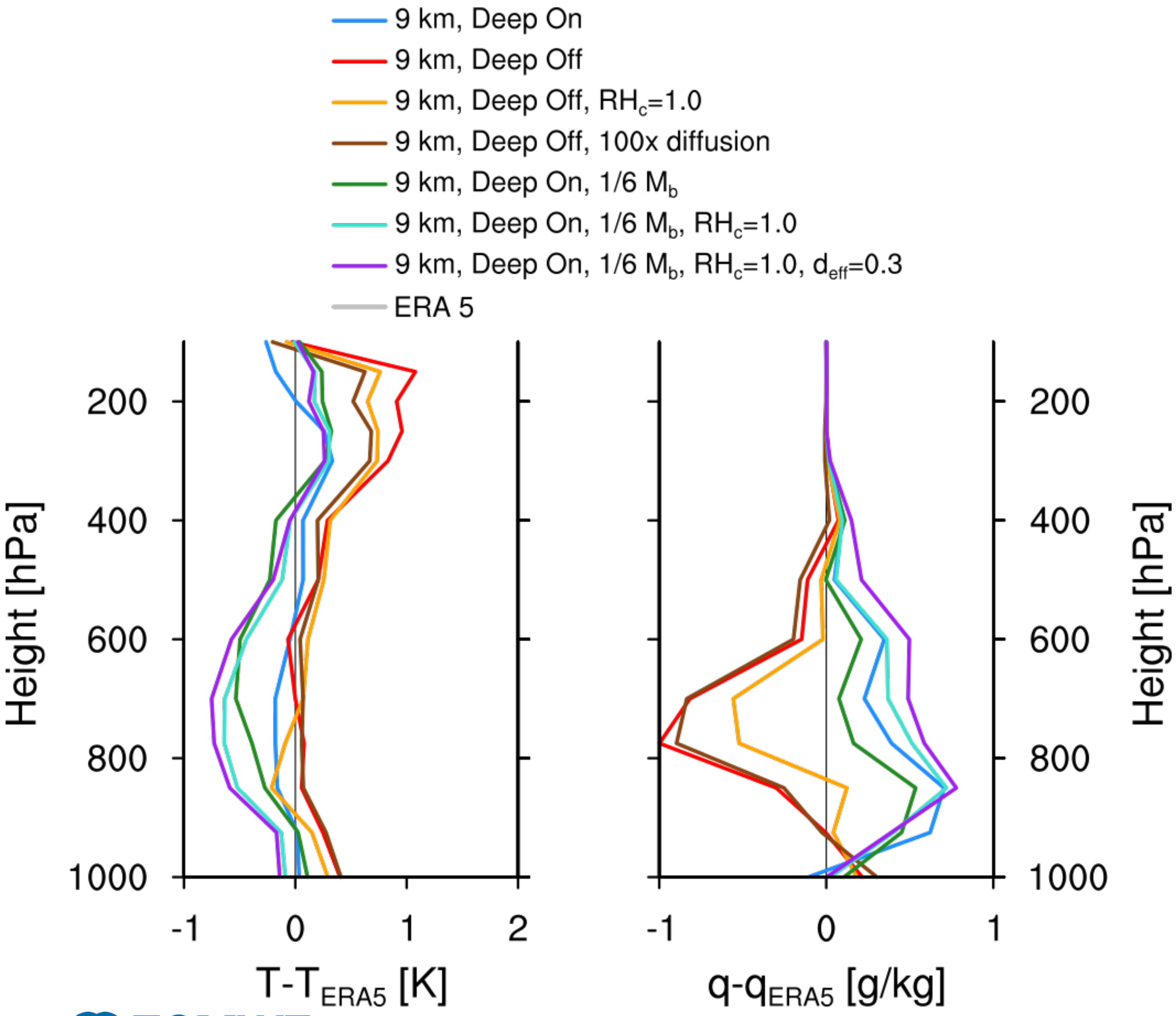
Cloud top height: analysed with satellite image simulator



- cloud top height best represented with Deep On
- but mid-level and shallow clouds best represented with increased hydrometeor detrainment

ECMWF

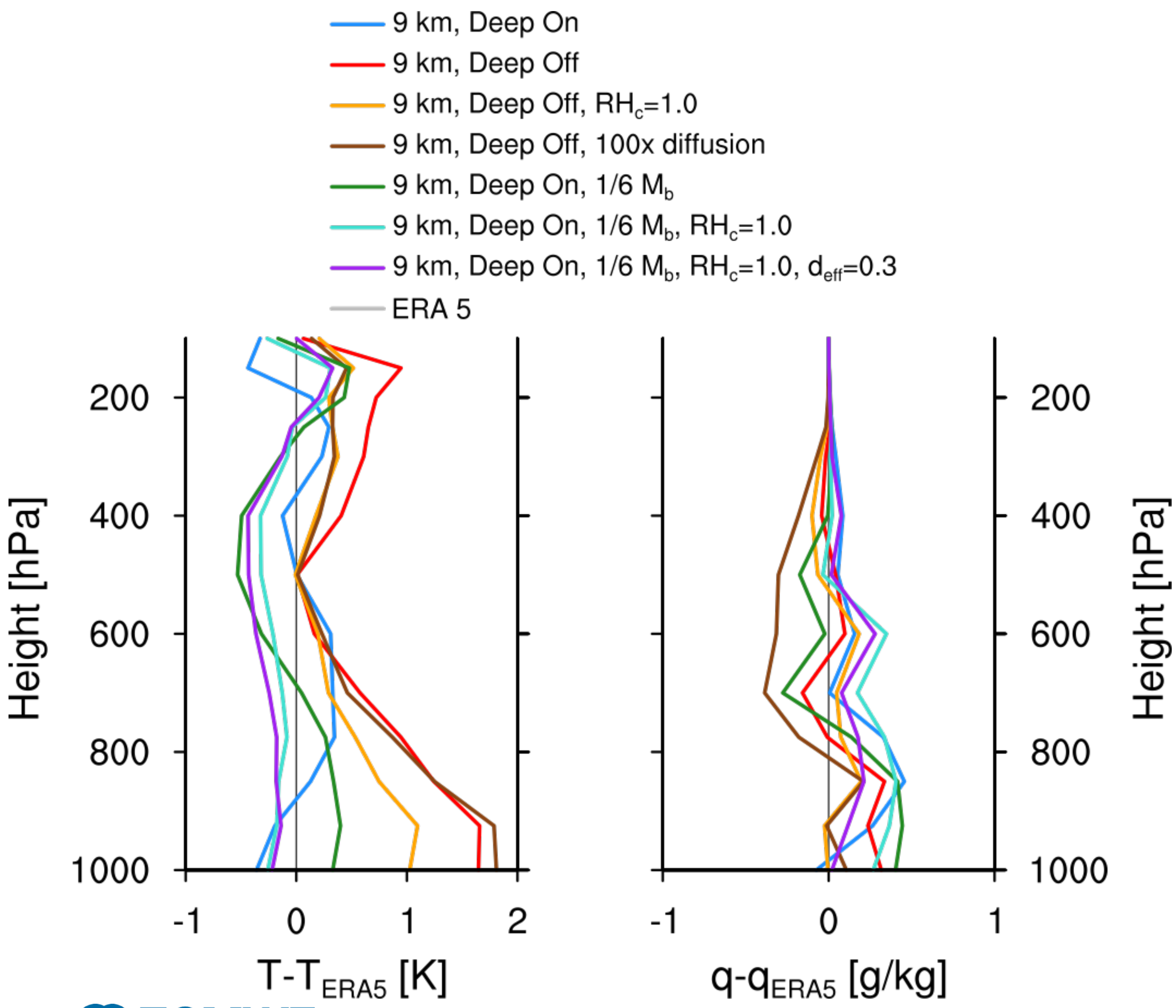
Mean vertical profiles (NH Pacific ITCZ)



- Deep Off: too dry above boundary layer
- Deep On: moister than ERA 5
- 1/6 M_b: too cold at 600 hPa
- RH_c=1.0: too cold and too moist at 800 hPa because of hydrometeor evaporation

ECMWF

Mean vertical profiles (South America)

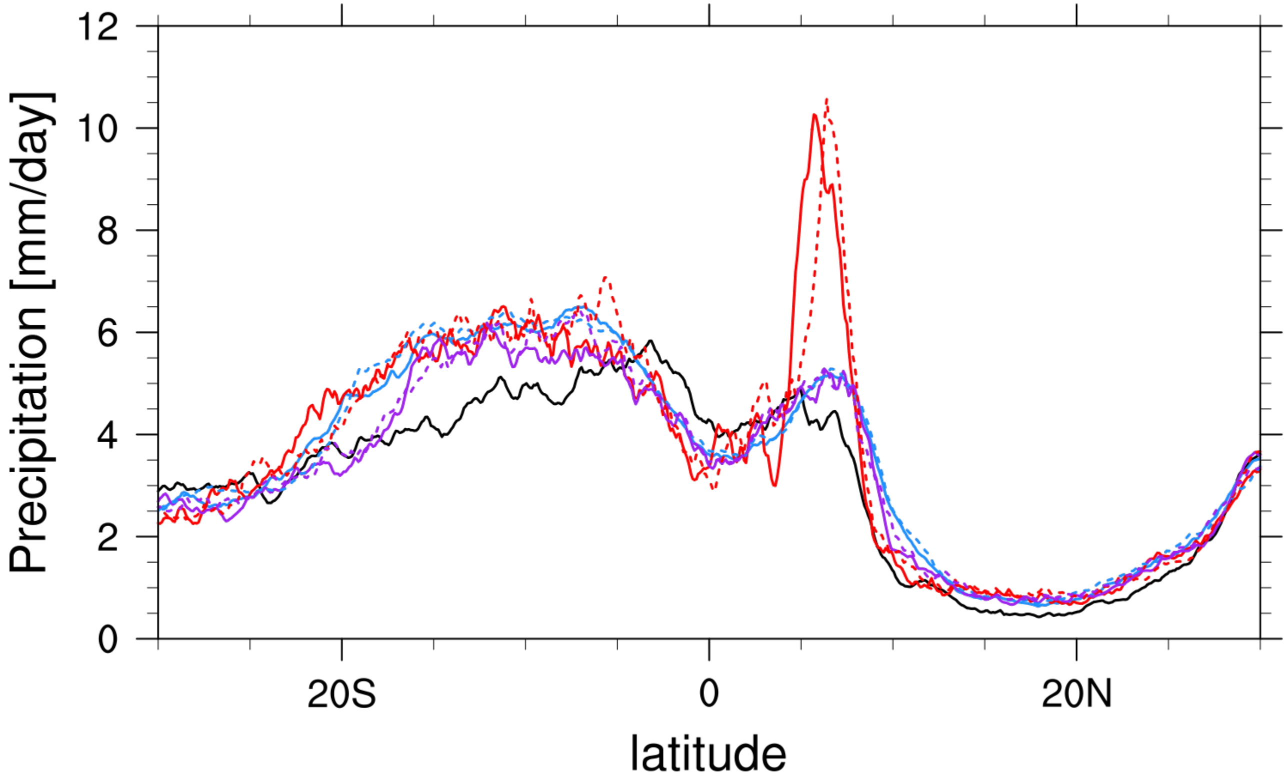


- Deep Off:
  much too warm over South America
- 1/6 M_b, RH_c=1.0 and d_{eff}=0.3:
  good agreement with ERA5

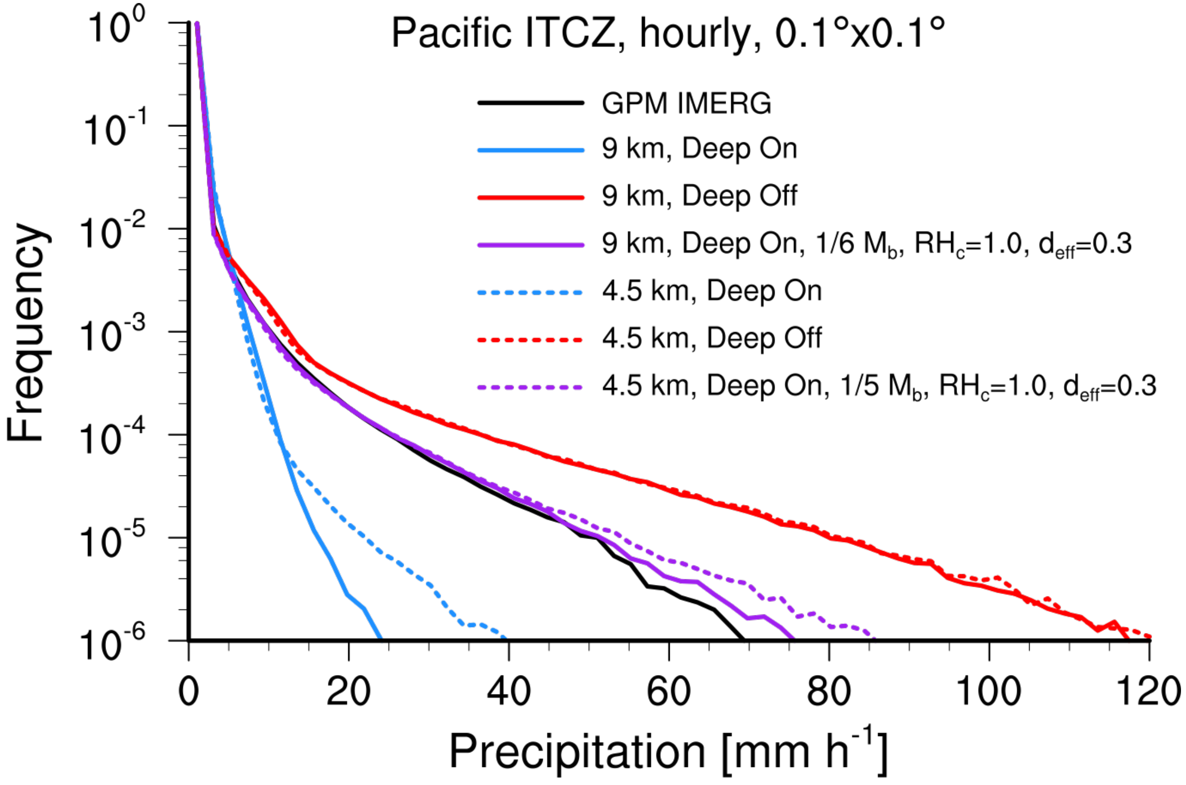
ECMWF

4.5 km vs 9 km resolution

- zonal mean precipitation shows no significant resolution dependencies



- Deep On & setups with reduced M_b: increase of precipitation intensity at 4.5 km



ECMWF

How to represent deep convection at km-scale resolutions?

- assumptions made in physics parametrisations need to be revisited
  ➔ example: microphysics scheme (areas with rainfall are starting to be resolved)

- turbulent mixing of updraft with environment is unresolved and underestimated by current IFS physics
  ➔ a new scheme is required that locally increases updraft mixing with the environment (e.g., TKE scheme)

- resolved deep convection is only triggered under very strong forcing (strong low-level convergence), when the atmosphere is already too unstable
  ➔ one possible solution is to keep the deep convection scheme slightly active

- sensitivity experiments succeed in finding a setup with realistic precipitation characteristics (zonal mean, intensity, spatial pattern) but fail to represent larger mesoscale convective systems (like squall lines)

ECMWF