Representation of clouds and precipitation in storm-resolving coupled global simulations

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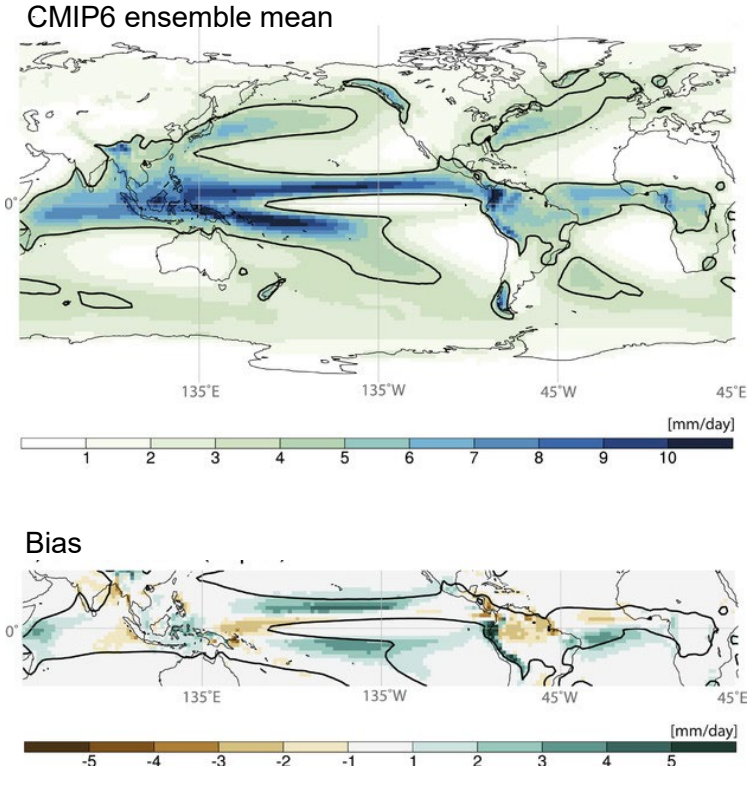
Well-known systematic biases in representing precipitation in climate models

Assessment of tropical precipitation over three generations of CMIP model

- No improvement
  - Seasonal cycle: double ITCZ and poorly represented monsoons
  - Largest precipitation associated with too shallow deep clouds
  - Diurnal cycle: too early maximum in precipitation amount and frequency
- Improvement in other aspects (e.g. mean spatial correlation, variability) but rate of improvement too slow

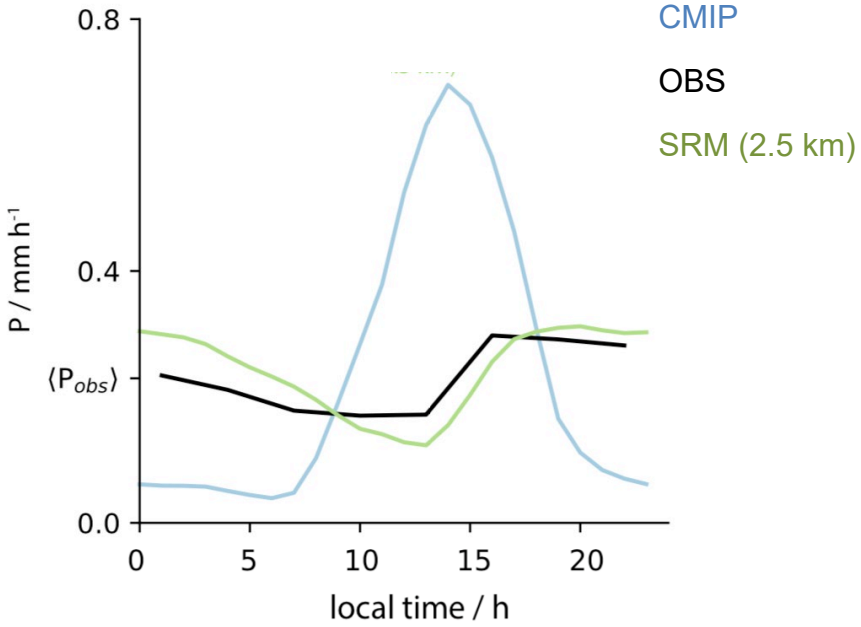


Precipitation

Fiedler et al. (2020, MWR)

Explicitly representing convection improves aspects of the precipitation distribution

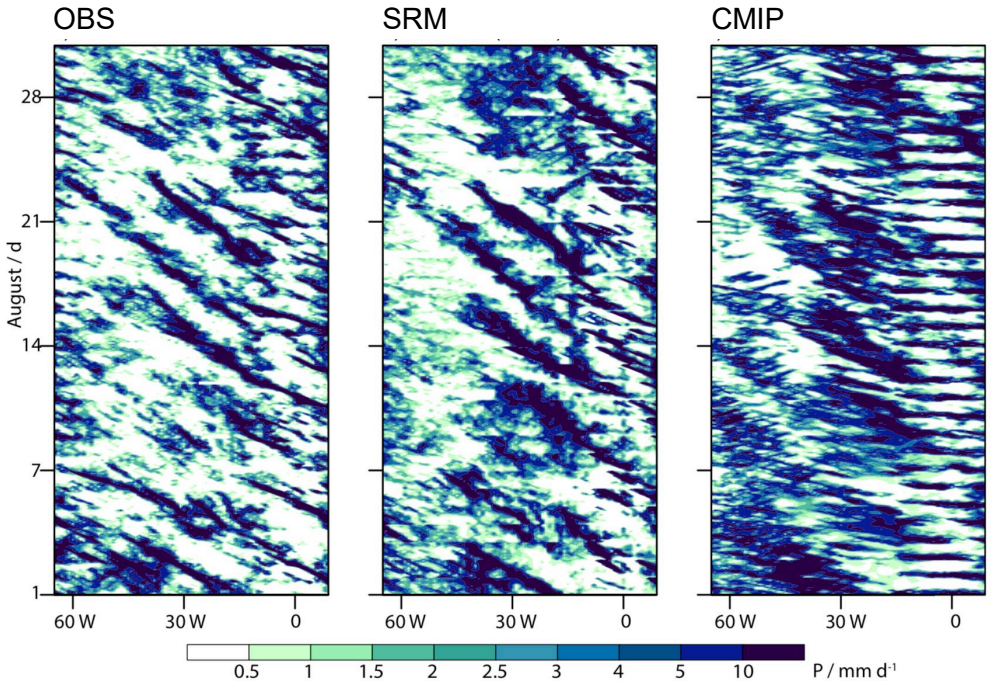
- Better precipitation diurnal cycle



Stevens et al. (2020, JRMSJ)

Explicitly representing convection improves aspects of the precipitation distribution

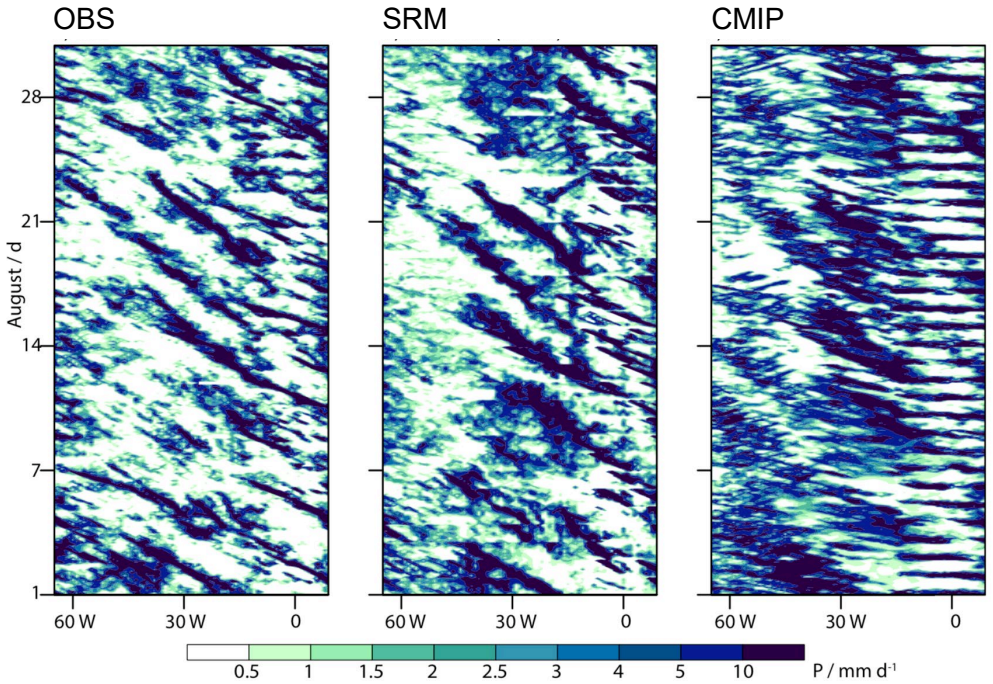
- Better precipitation diurnal cycle
- Better propagation



Stevens et al. (2020, JRMSJ)

Explicitly representing convection improves aspects of the precipitation distribution

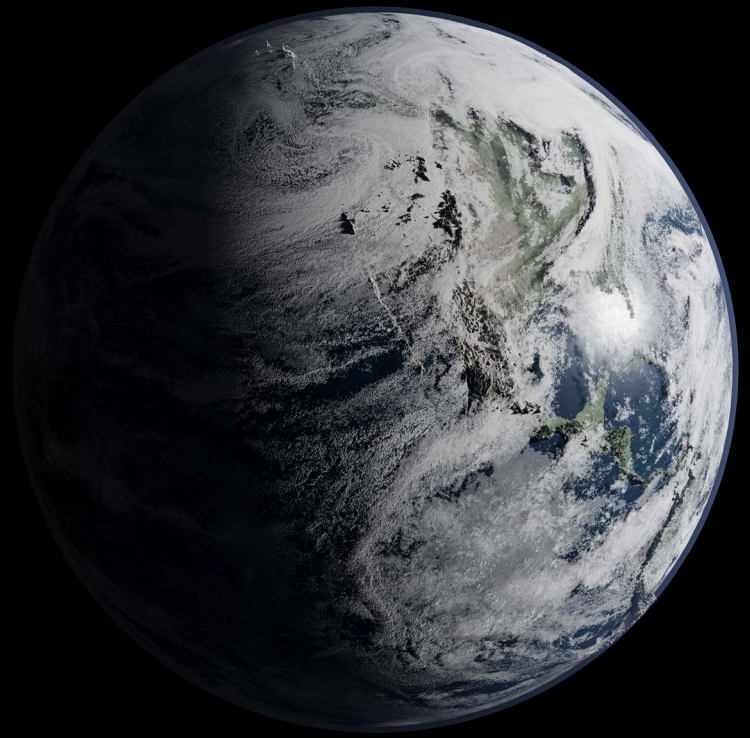
- Better precipitation diurnal cycle
- Better propagation
- Better frequency distribution but overestimate extremes
- No much impact on the mean



Stevens et al. (2020, JRMSJ)

Global coupled storm-resolving (km-scale) simulations

- To which extent do such simulations reduce well-known systematic biases out-of-the box?
- Which aspects of the climate system are sensitive to subkilometer processes?
- Where is turbulence/shallow convection/microphysics/ocean mixing more important than explicitly resolving convection?



Outline

1. Tropical precipitation

   Biases mostly solved over land but ocean remains delicate

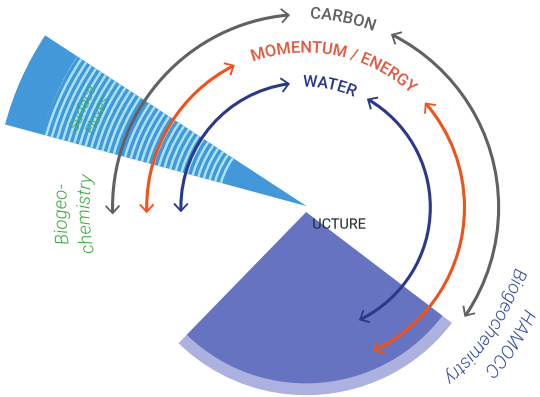
2. Tropical cloud distribution

   Very well reproduced, except for shallow clouds (no surprise)

3. Biases and their relationship to unresolved processes

Model: ICON-SAPPHIRE (ICON-S)

- Target representation of Earth System at a grid spacing finer than 10 km
- dx=5 km, global, ocean-atmosphere, 1 year
- Atmosphere
  Radiation: PSRAD (Pincus and Stevens 2013)
  Microphysics: one moment, 6 hydrometeors (Baldauf et al. 2011)
  Turbulence (Smagorinsky 1963)
- Land
  Only physical land
- Ocean
  Vertical turbulent mixing: TKE (Korn et al. 2021)
  Velocity dissipation: combined harmonic/biharmonic Laplace operator (Korn et al. 2021)



Hohenegger et al. (2022, GMDD)

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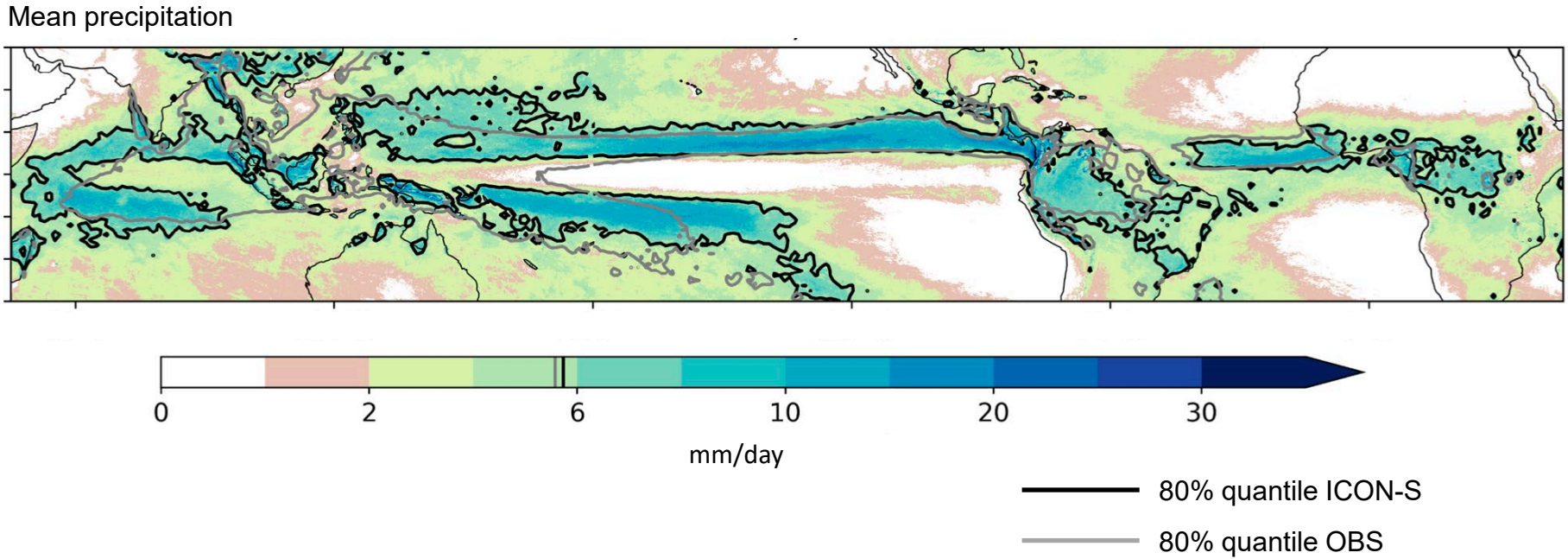
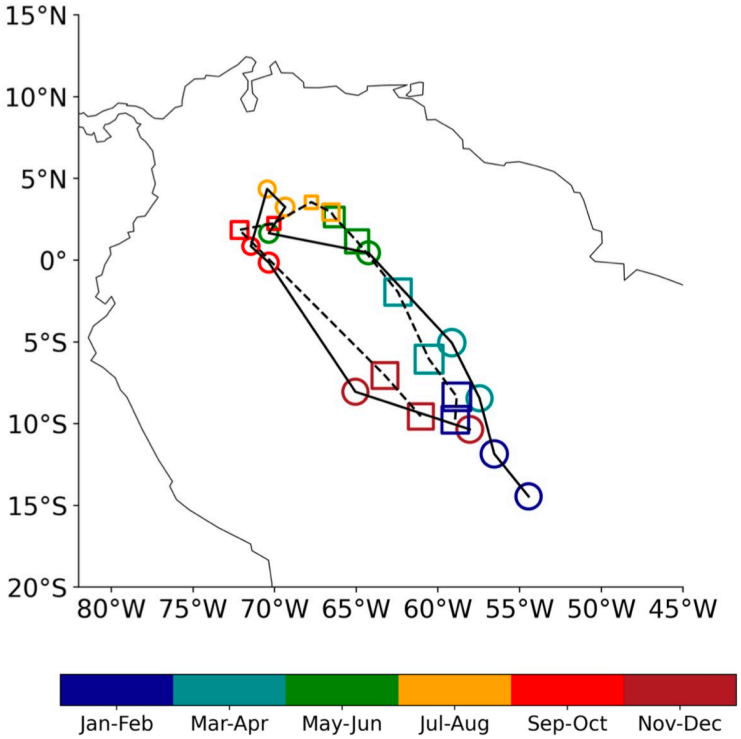
Precipitation well captured over land, obvious biases over ocean



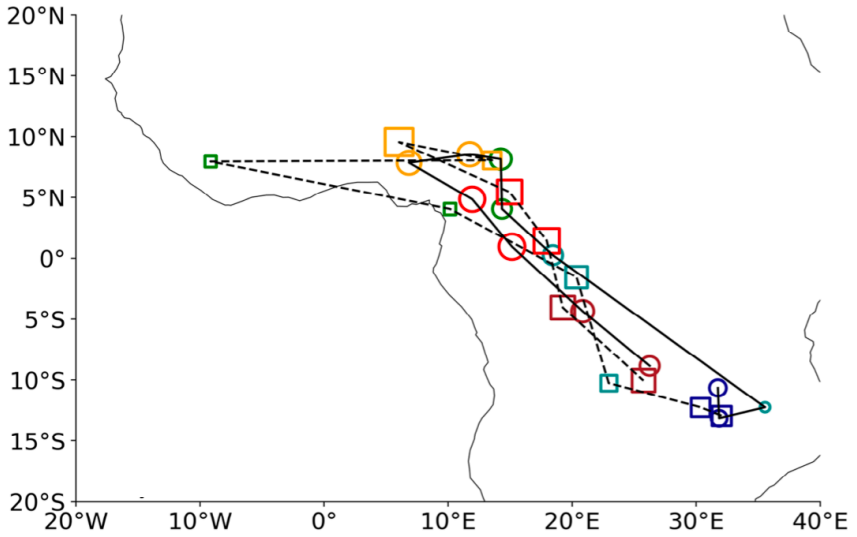
Segura, Hohenegger, Wengel, Stevens (submitted)

Seasonal migration of rainbelts over land extremely well captured

South America



Africa



Segura, Hohenegger, Wengel, Stevens (submitted)

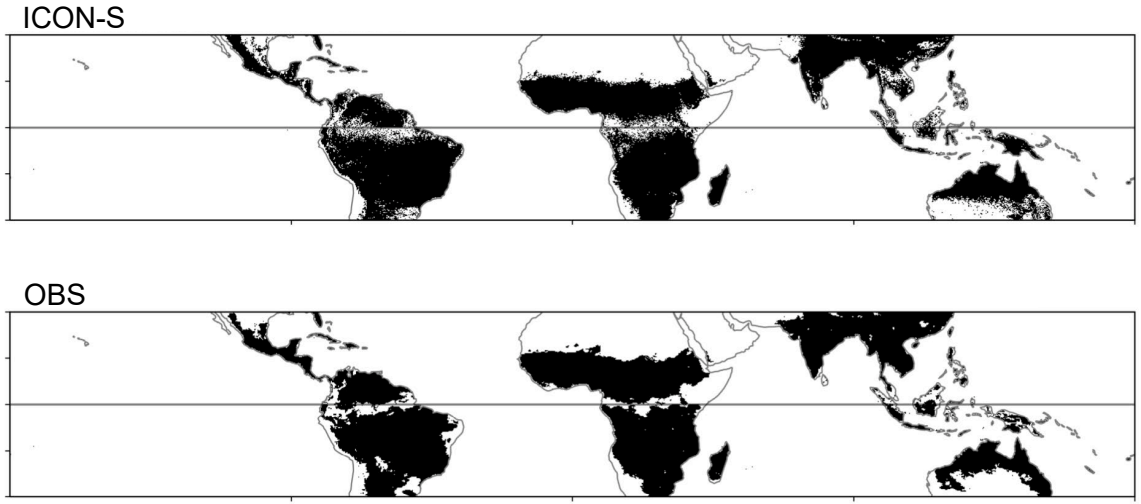
Summer monsoon area looks realistic

- Area (10^7 km^2)

  ICON-S: 3.49
  OBS: 3.37 ± 0.09

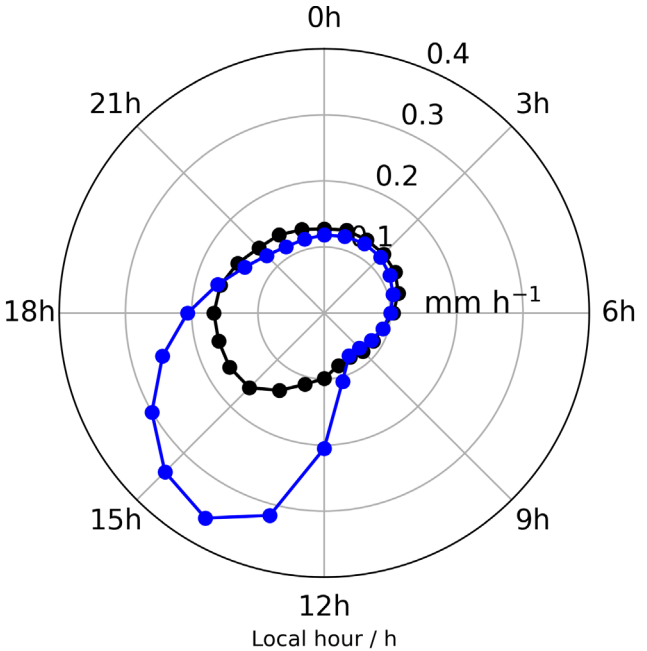
- Intensity (mm day^{-1})

  ICON-S: 7.78
  OBS: 6.78 ± 0.17



Diurnal cycle: good timing but amplitude too strong

- Wrong amplitude of diurnal cycle doesn‘t seem to matter to capture mean precipitation characteristics over land



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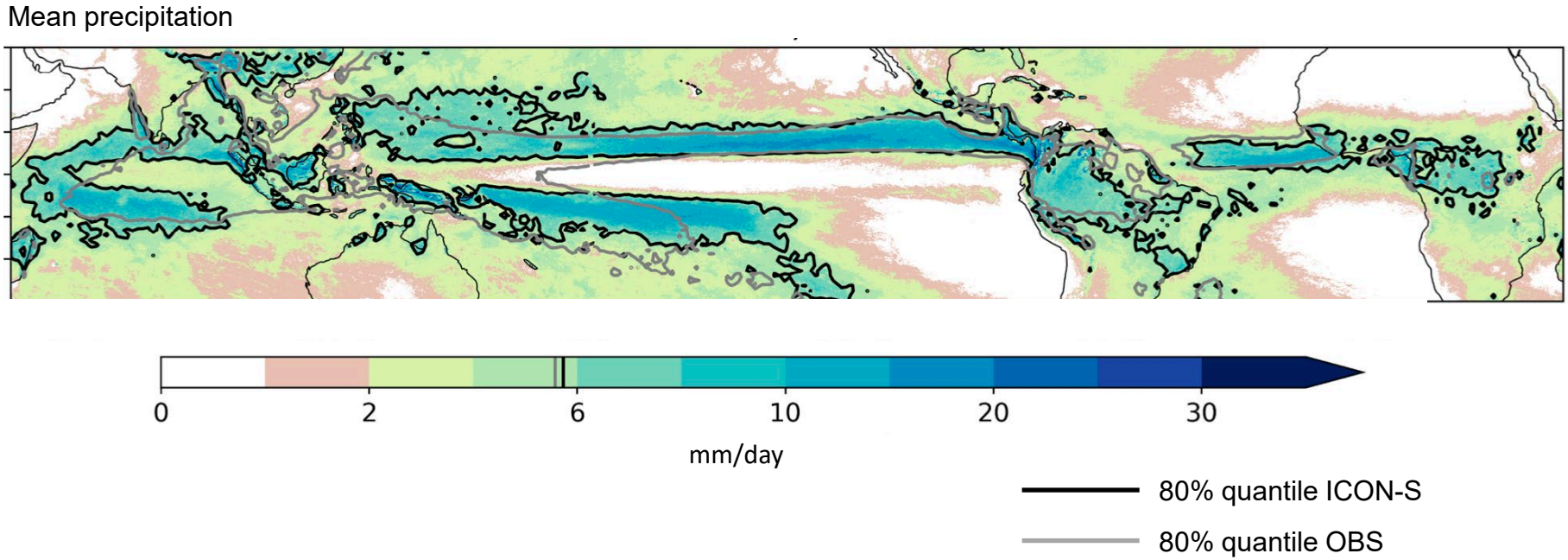
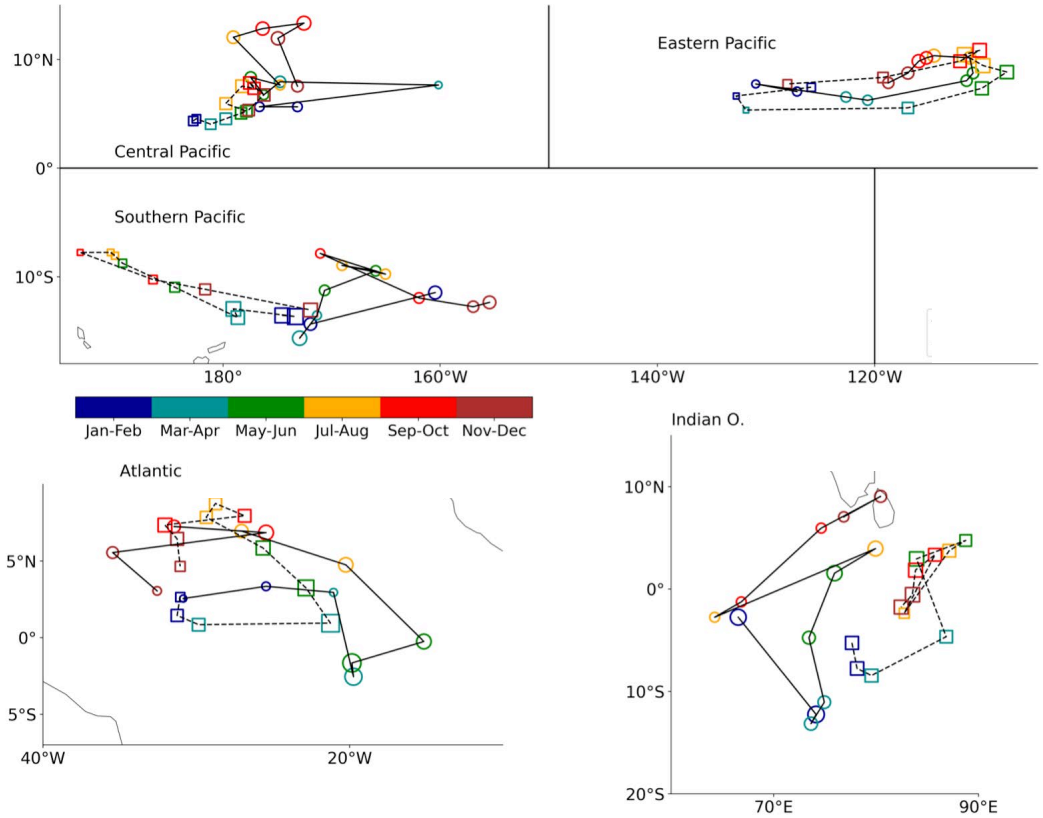


Segura, Hohenegger, Wengel, Stevens (submitted)

Seasonal migration: good and bad

- Agreement depends upon ocean basin
- Again obvious problems with southern Pacific and Indian Ocean



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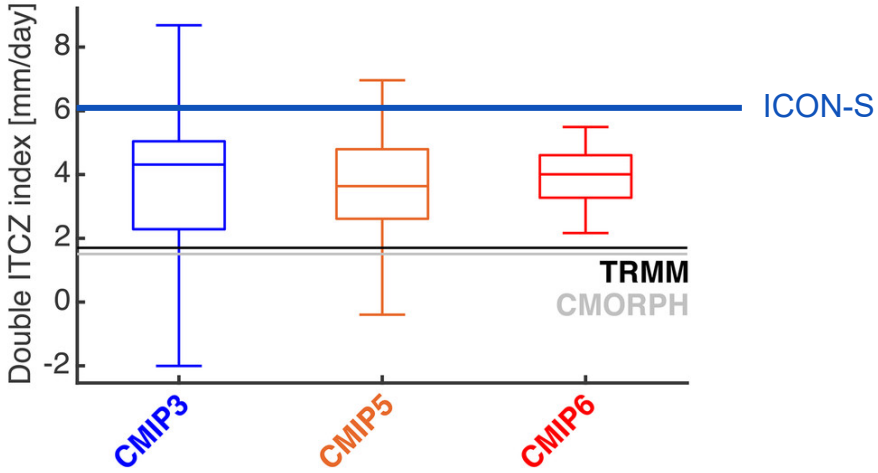
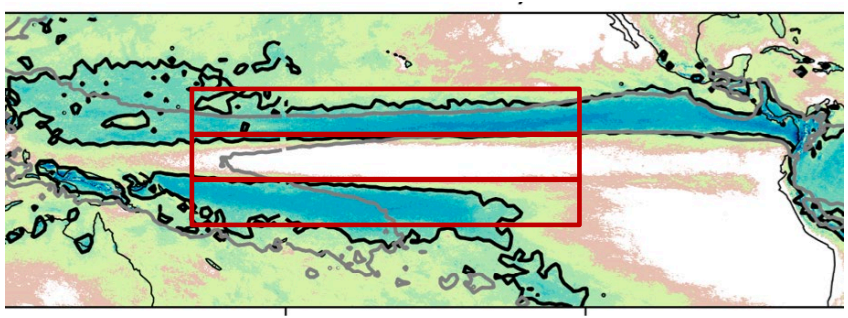
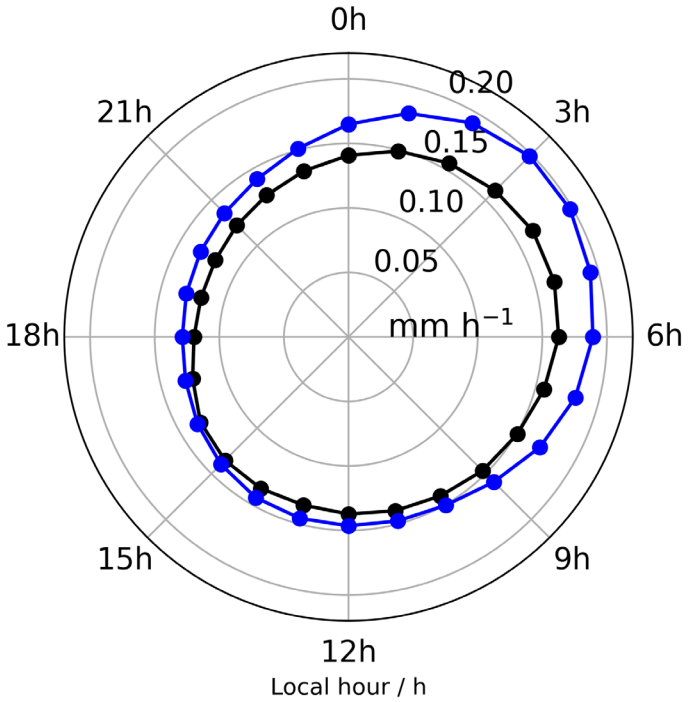
Strong double ITCZ



Fiedler et al. (2020, MWR)



Diurnal cycle: well captured, again slight tendency to overestimate amplitude

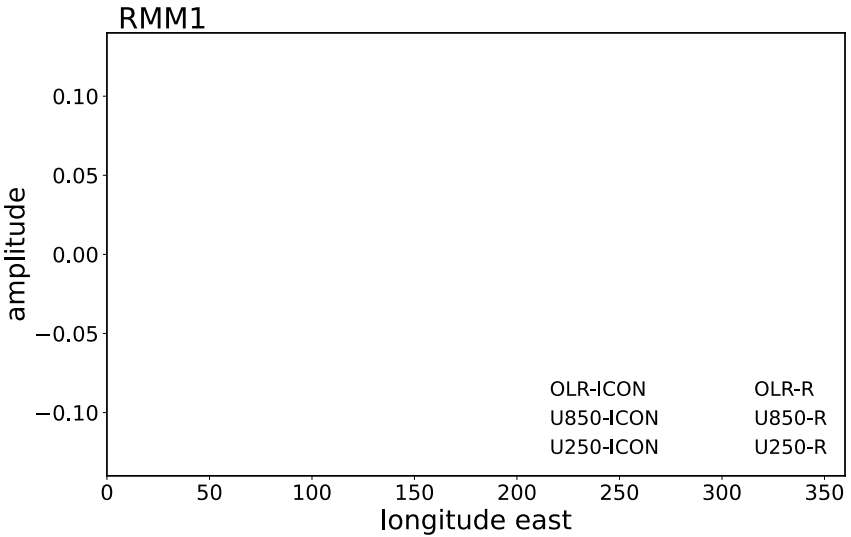


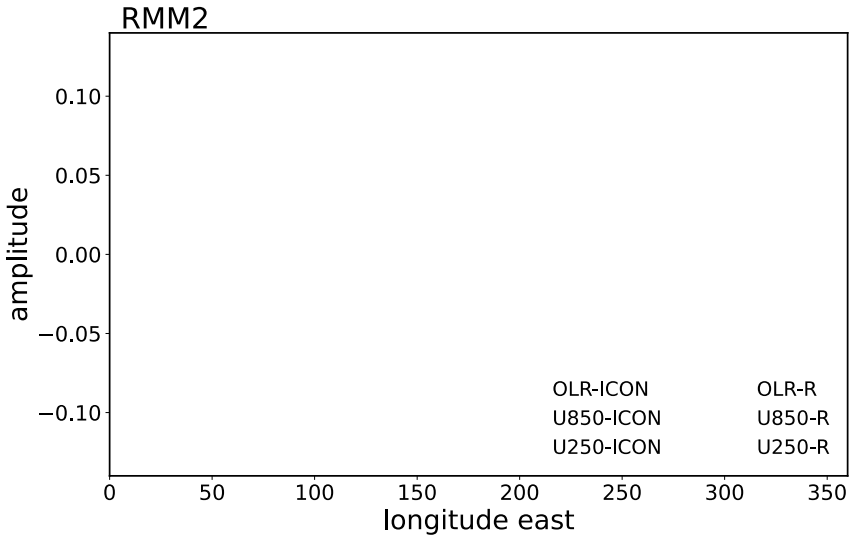
ICON-S

OBS

Segura, Hohenegger, Wengel, Stevens (submitted)

MJO: surprisingly well captured





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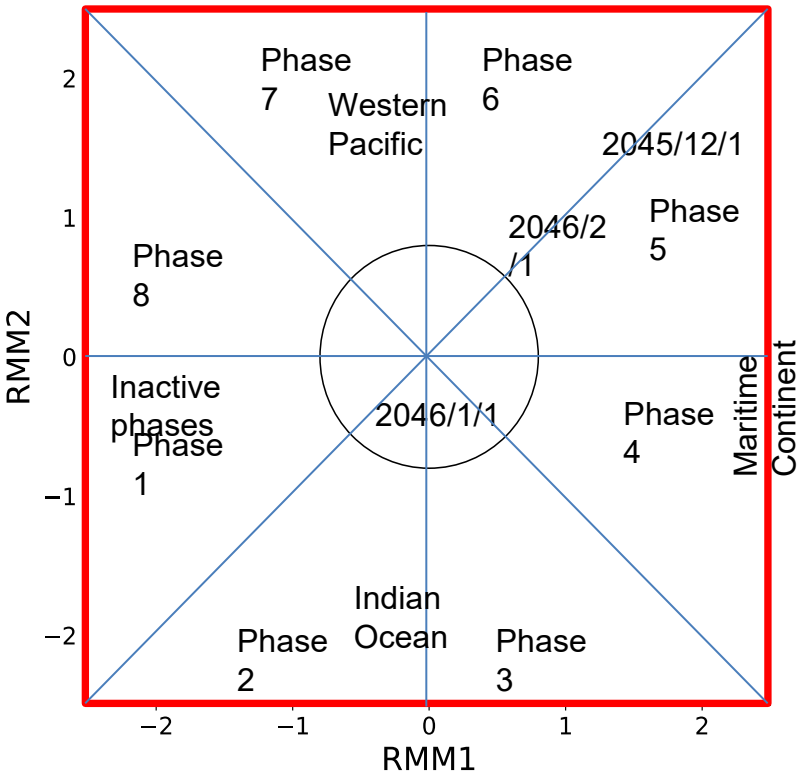
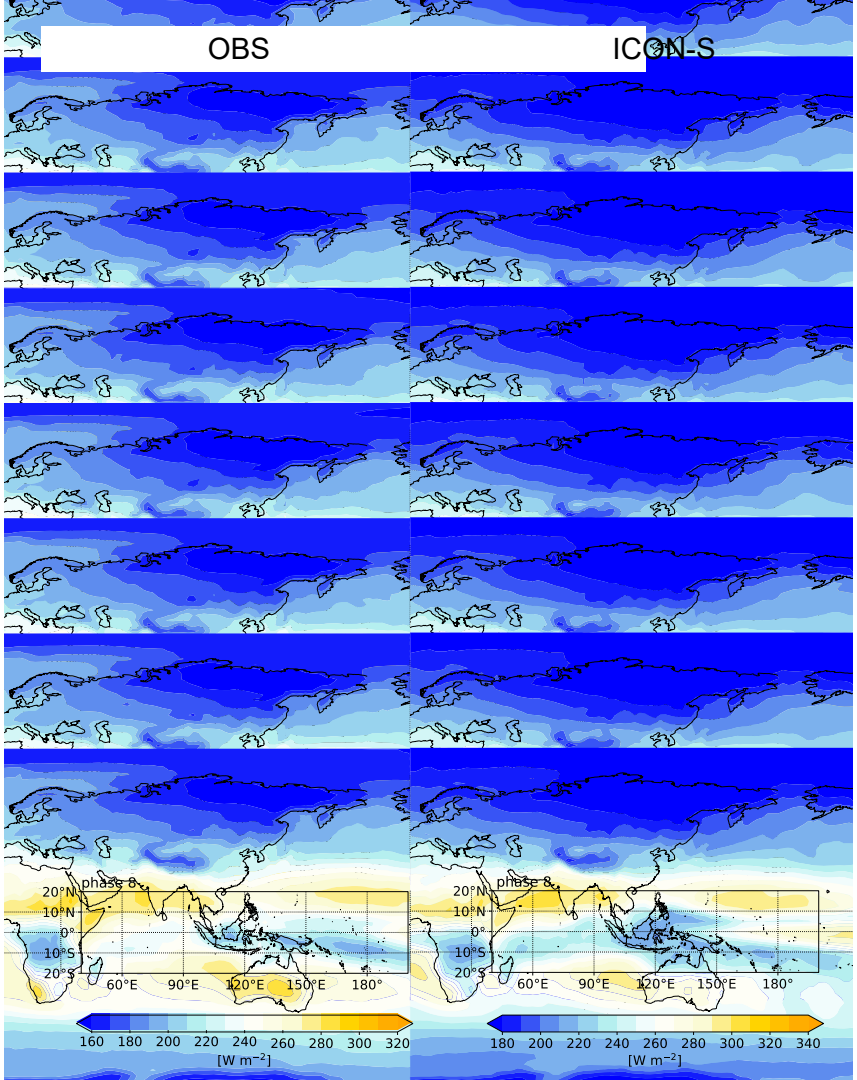
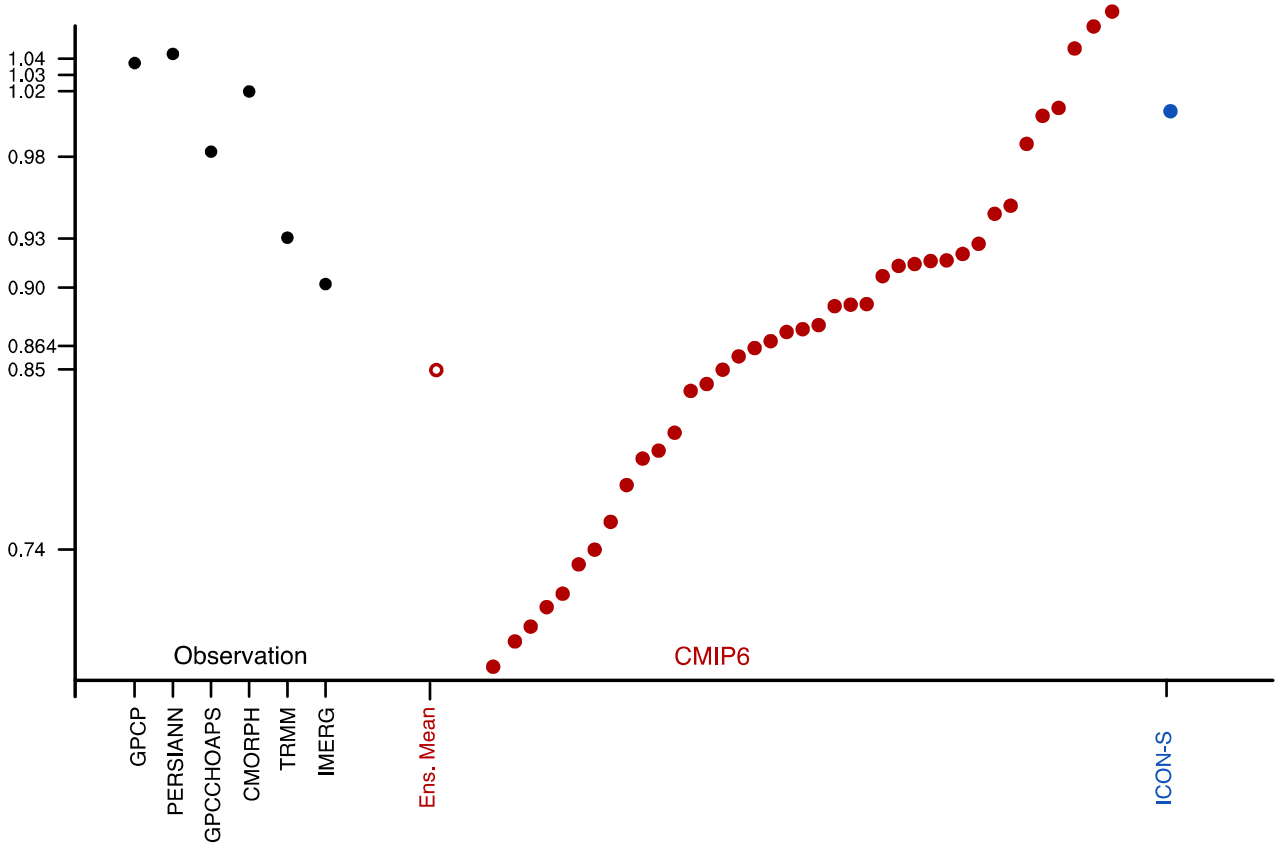




Tamaki Suematsu (U. Tokyo)

Precipitation partioning between land and ocean: correctly captured



Hohenegger and Stevens (2022, ADV)

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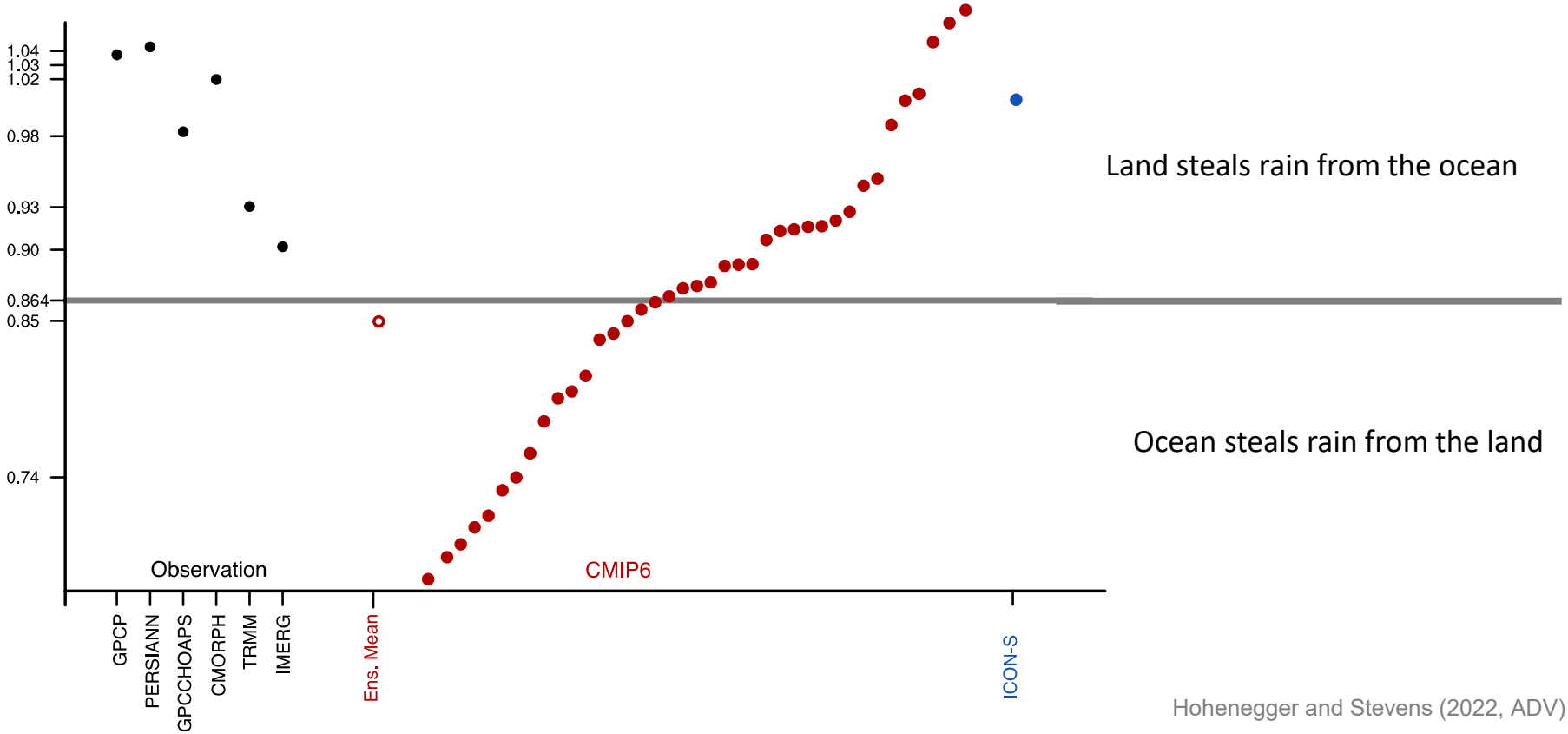
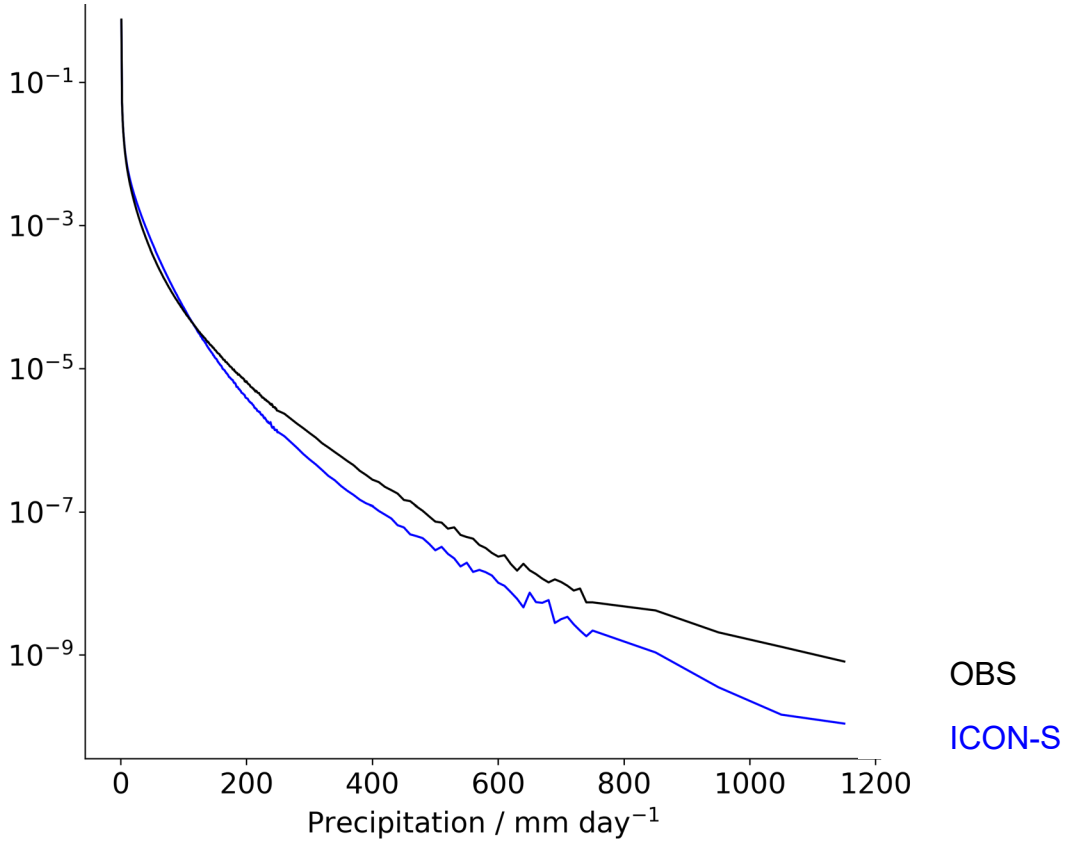


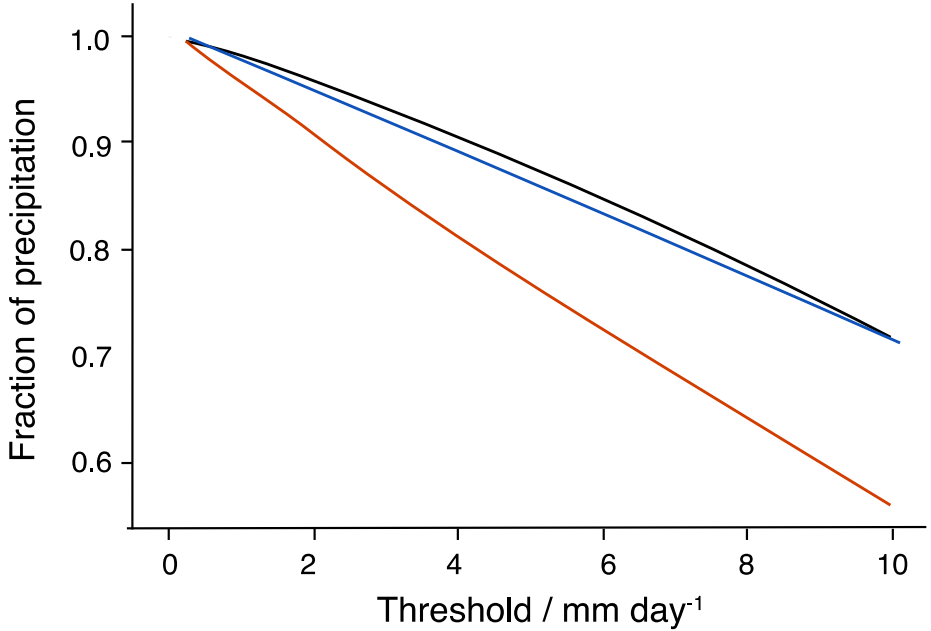
Hohenegger and Stevens (2022, ADV)

Probability distribution function of precipitation well captured



Hans Segura

How it rains is better captured in ICON-S



ICON-S

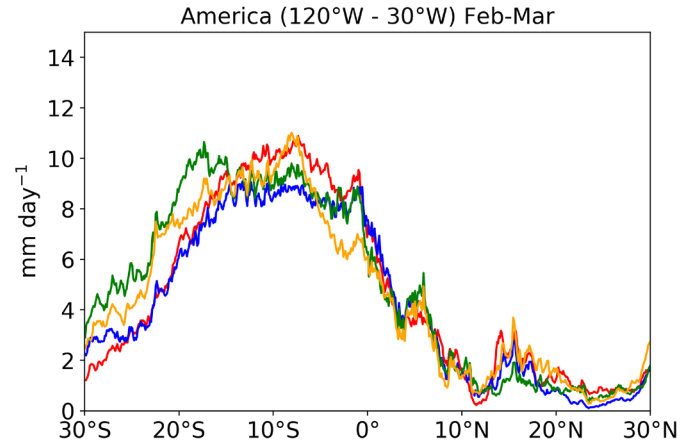
OBS

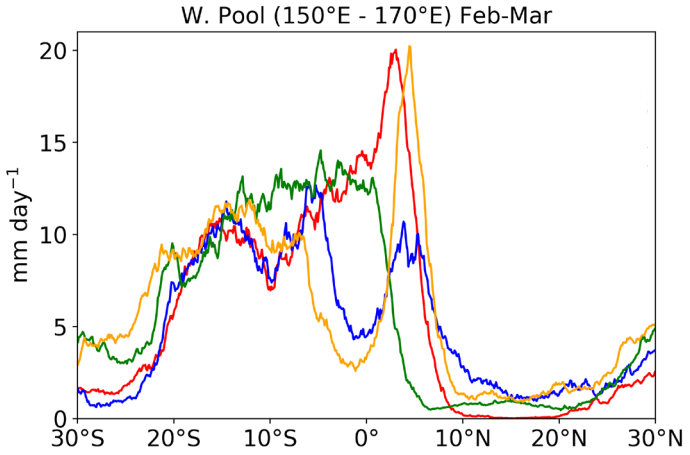
CMIP

Hans Segura and Christian Jakob (U Monash)

Conclusions tropical precipitation

- Over land, most known systematic biases are solved
- Over ocean, systematic biases persist over western Pacific and Indian Ocean with a pronounced double ITCZ
- Other systematic biases that are sovled: drizzle problem, precipitation partitioning, timing of the diurnal cycle





Plot Hans Segura

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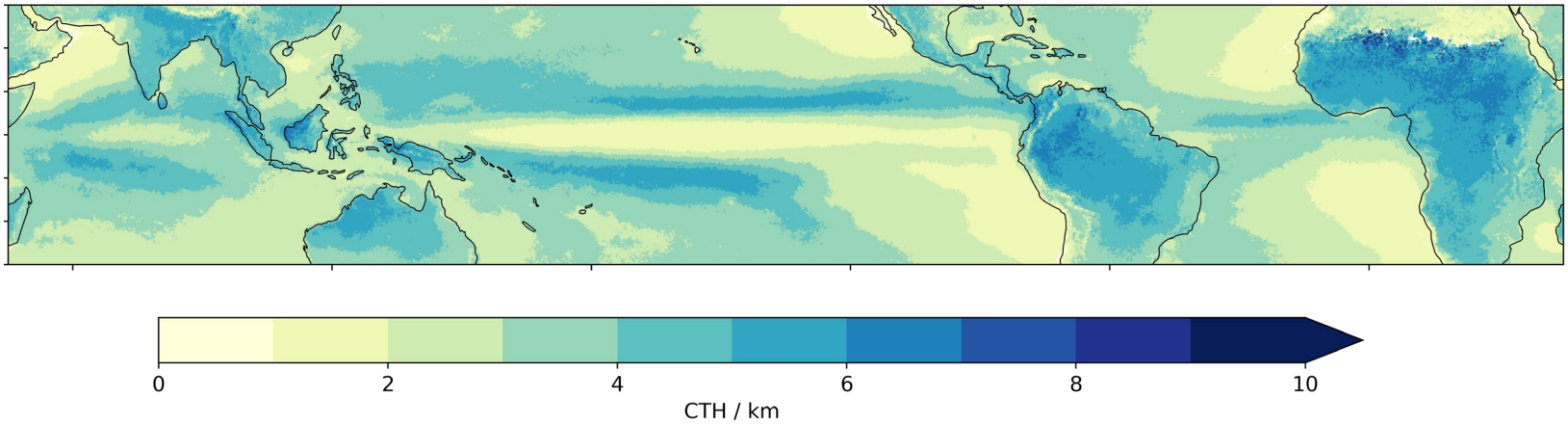
3. Biases and their relatinoship to unresolved processes

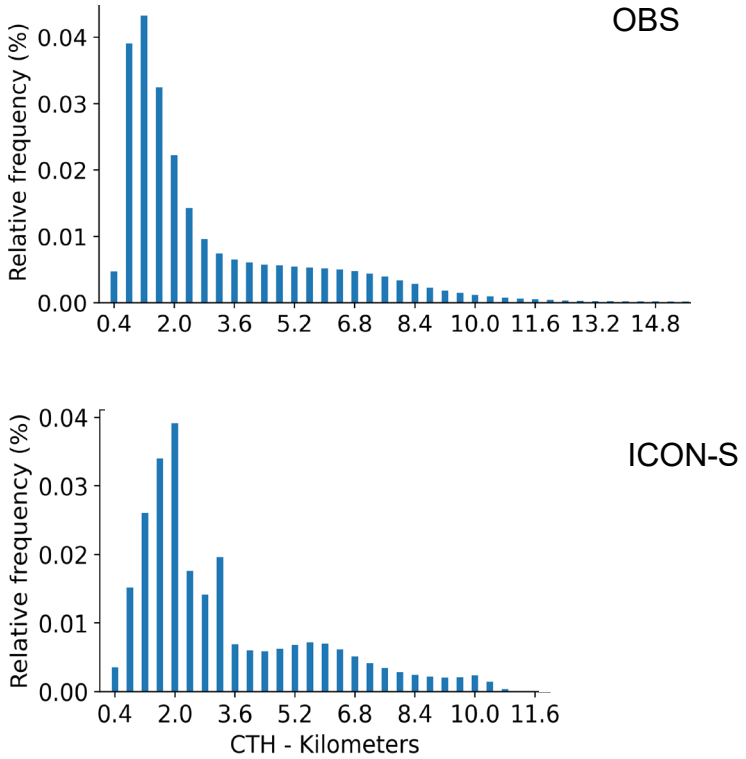
Mean cloud top height



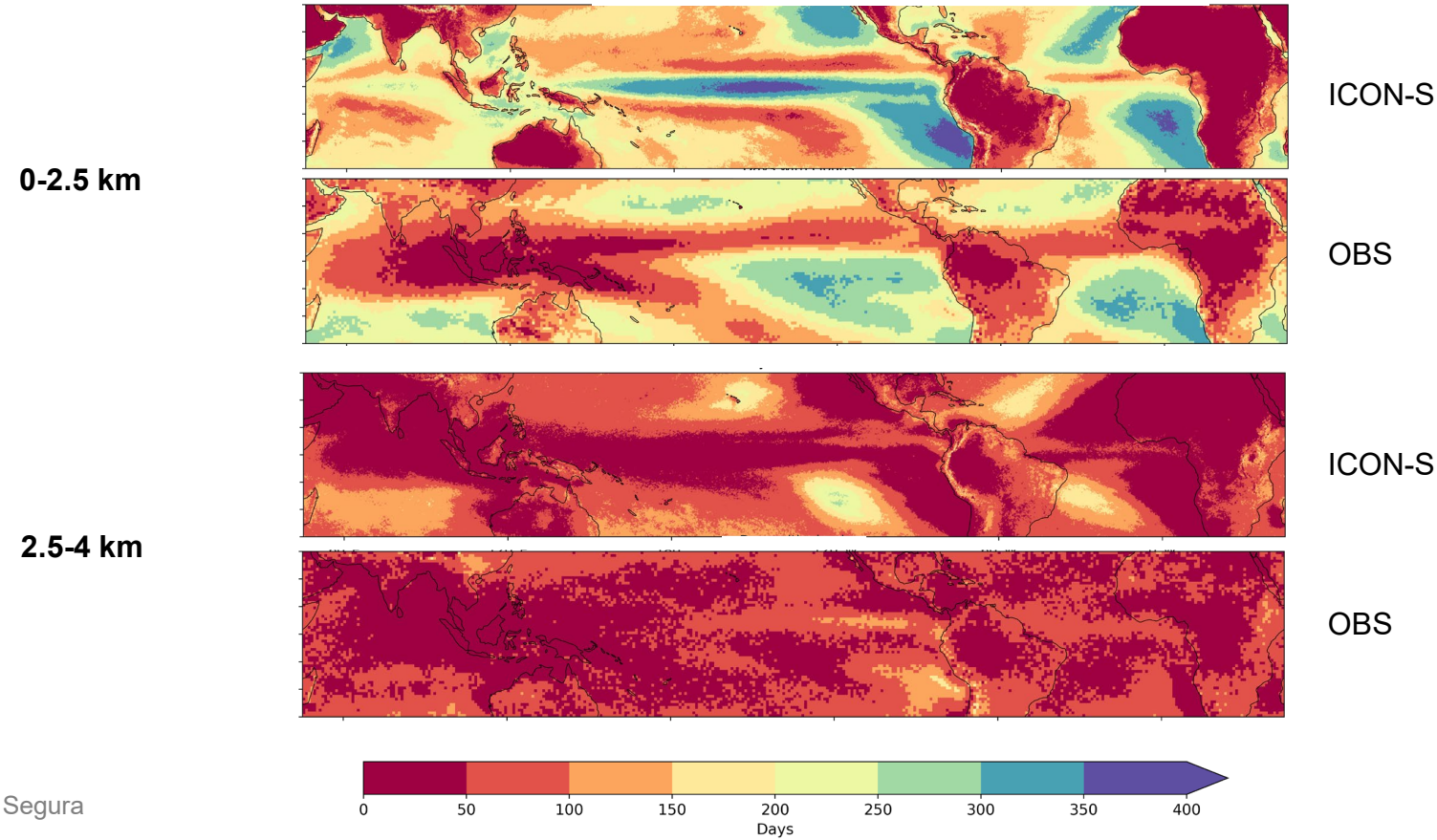
Hans Segura

Cloud top height distribution ocean: 3 modes, generally well reproduced

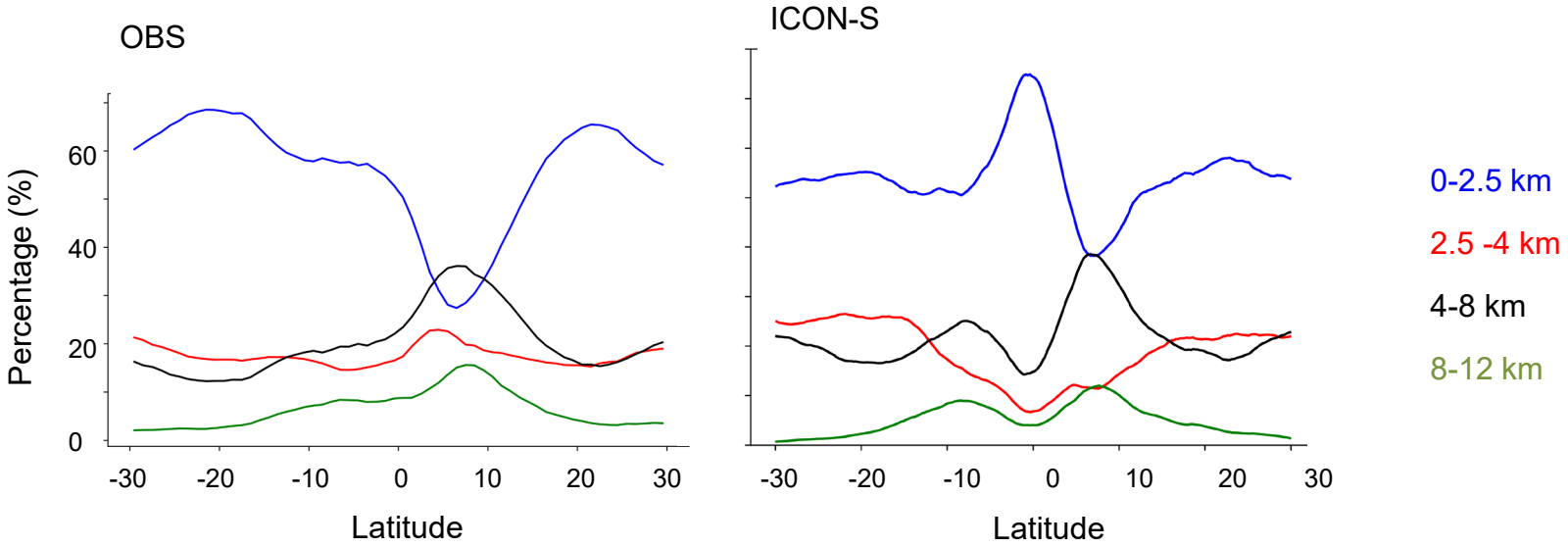
Type	OBS	ICON-S
All	80	97
< 2.5 km	56	54
2.5-4 km	18	19
4-8 km	20	22
> 8 km	6	5



Cloud top height distribution: equator stands out



Cloud top height distribution: equator region stands out



Conclusions tropical clouds

- General overestimation of clouds
- 3 modes, partioning well captured
- Precipitation biases reflected in the cloud field

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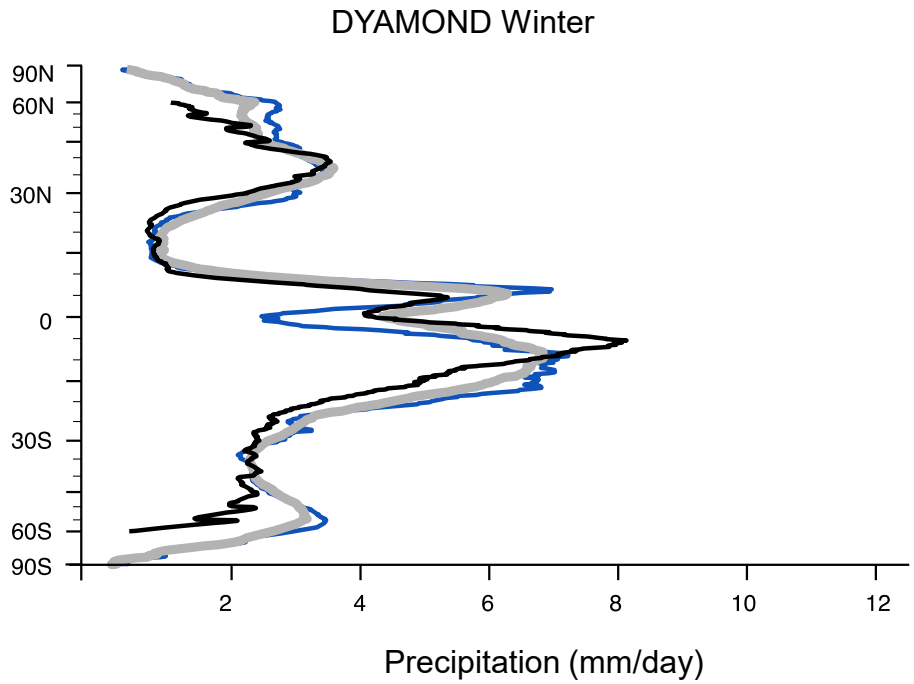
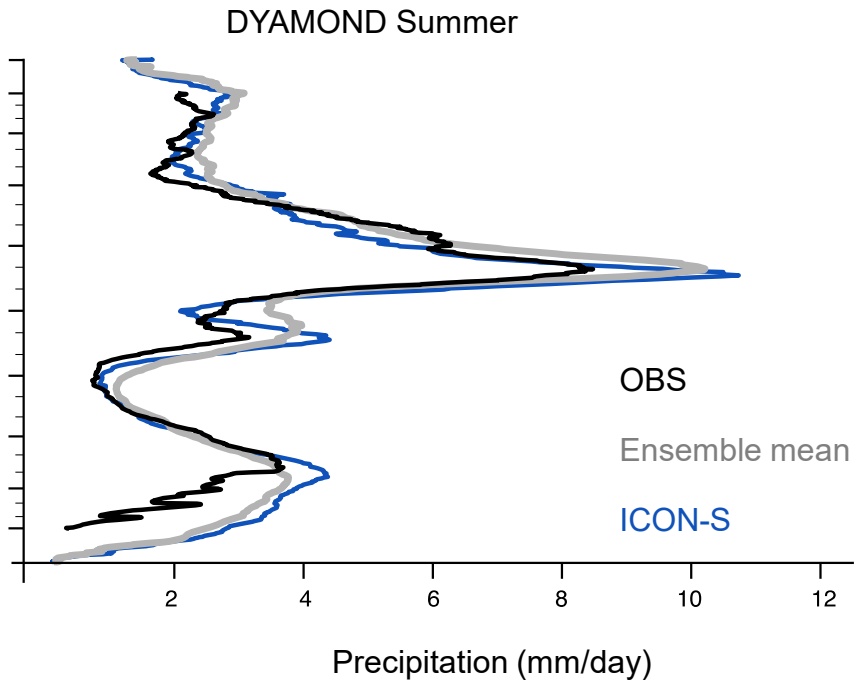
Oceanic ITCZ: will it also be a canonical problem of SRMs?

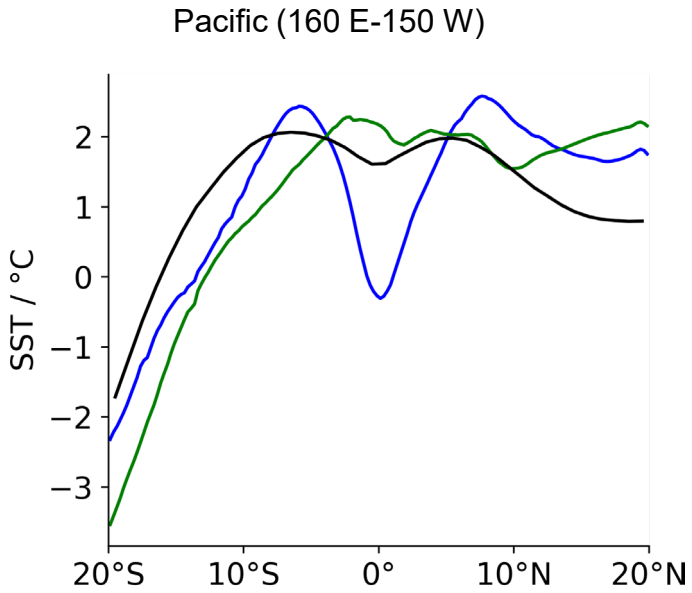




Hohenegger et al. (2022, GMDD)

Pacific and Indo-ocean biases: role of SST

- SST is too cold at the equator
- Why is SST too cold?



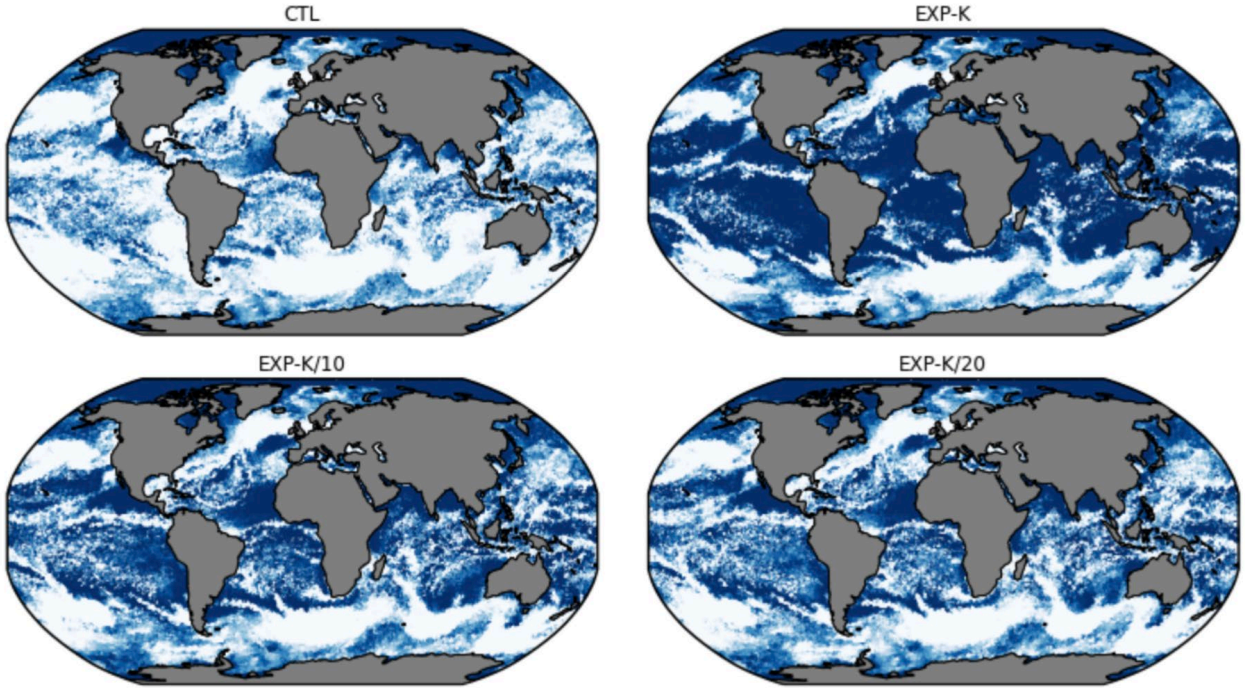
ICON-S

OBS

Segura, Hohenegger, Wengel, Stevens (submitted)

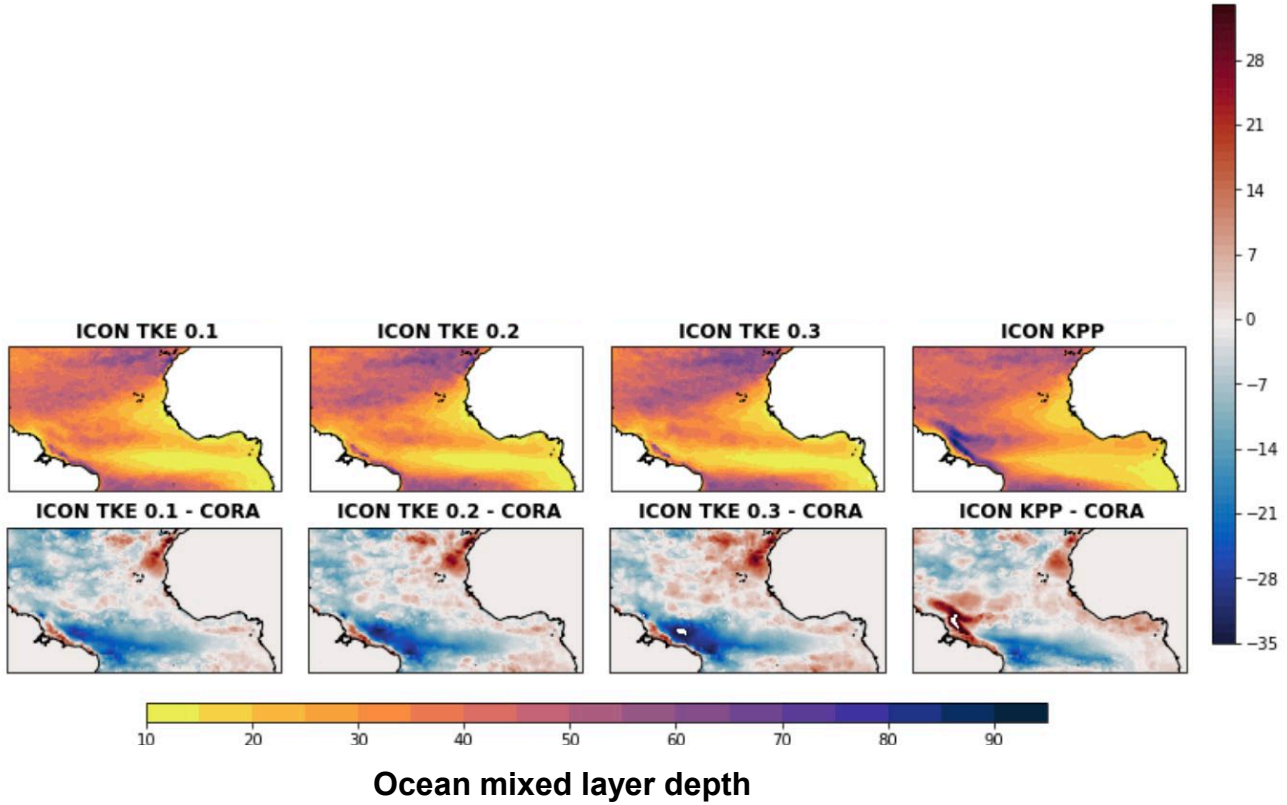
Too much shallow clouds?

- No shallow Cu parameterization
- Not enough ventilation in Smagorinsky
- ICON-S is too cold (1.4 K)



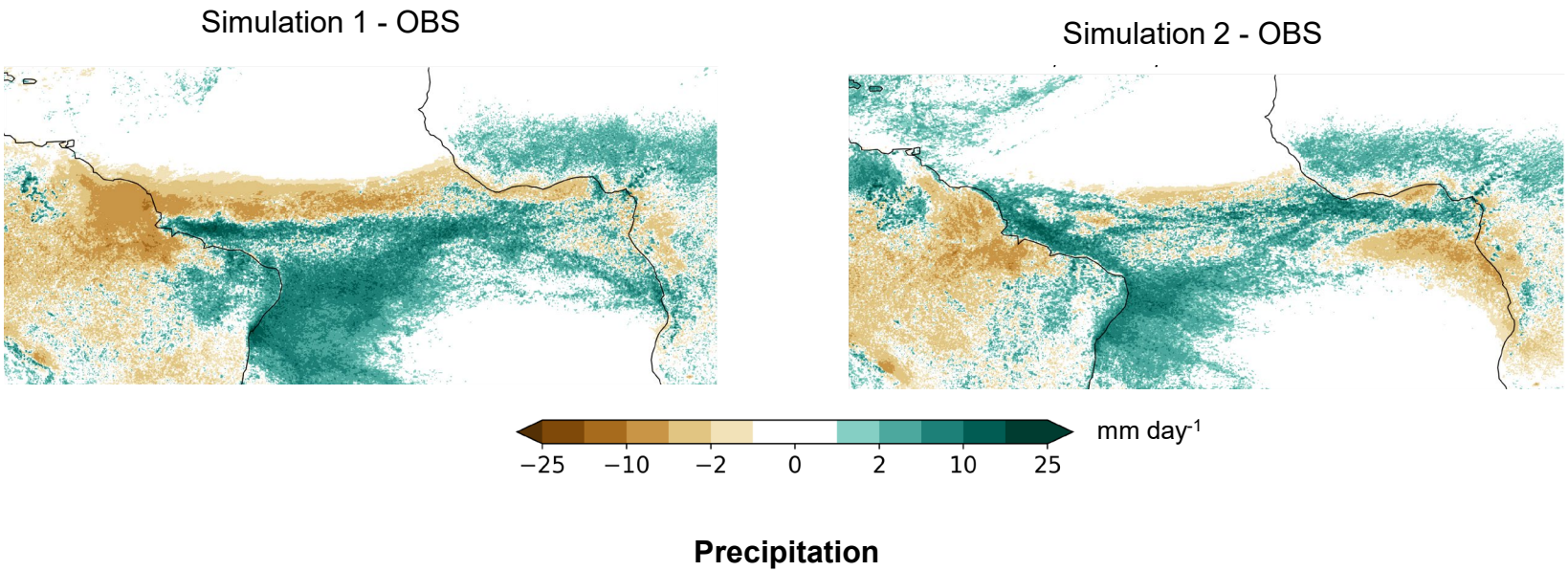
Wrong mixing in the ocean?

- Too shallow ocean mixed layers
- Decoupling
- No clear parameter setting yet



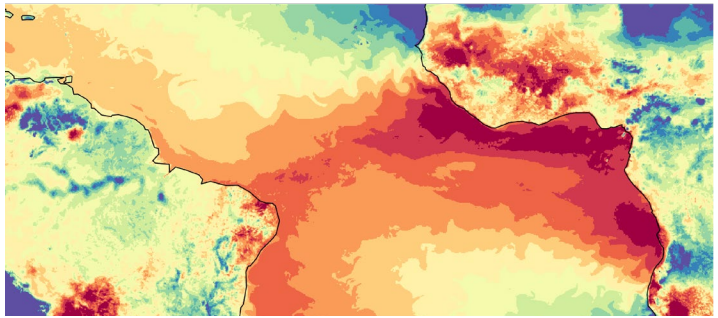
A. Koldunov (AWI) et al.

Making the problem worse: Unexpected high coupling sensitivity

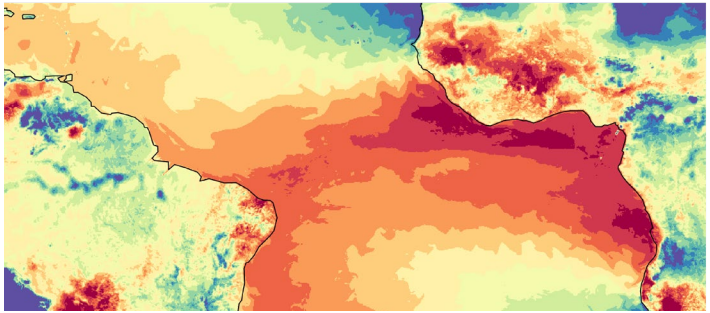


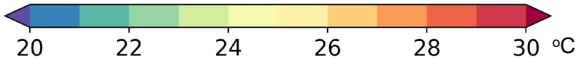
Making the problem worse: Unexpected high coupling sensitivity

Simulation 1



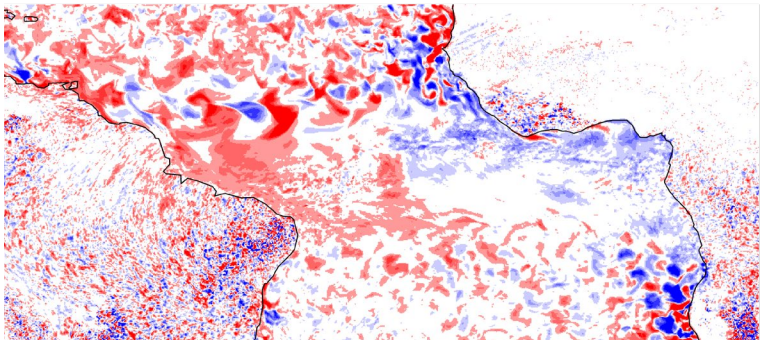
Simulation 2

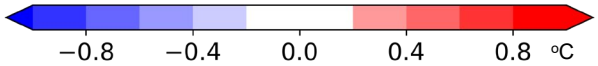




Surface Temperature

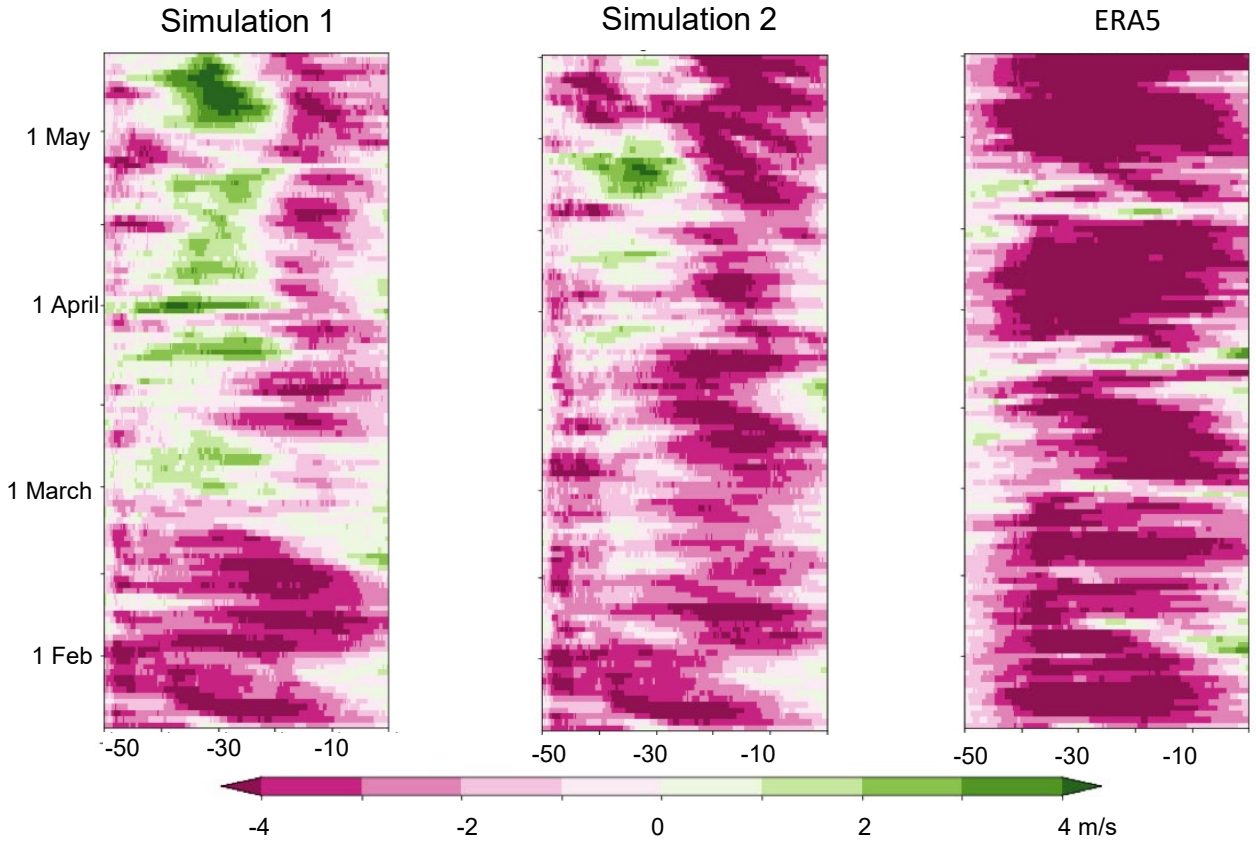
Simulation 2- Simuation 1





Segura, Bastin, Praturi, Shevchenko, Winkler

Unexpected high coupling sensitivity: wind reverseal



Zonal wind

Conclusions

- Over land, most known systematic biases are solved, land precipitation is also very robust to model changes
- Over ocean, systematic biases persist over western Pacific and Indian Ocean with a pronounced double ITCZ and a too dry equator.
- Link to too cold SST, consistent with a too large cloud cover and too shallow ocean mixed layer. Problem complicated by a strong sensitivity to underlying SST
- Other systematic biases that are sovled: drizzle problem, precipitation partitioning, timing of the diurnal cycle
- Cloud biases reflect precipitation biases with a general overestimation of cloud cover
- In terms of representation of subkilometer processes: shallow clouds and ocean mixing are weak spots