Evaluation of the tropical upper tropospheric cloudiness simulated by the convection permitting DYAMOND models

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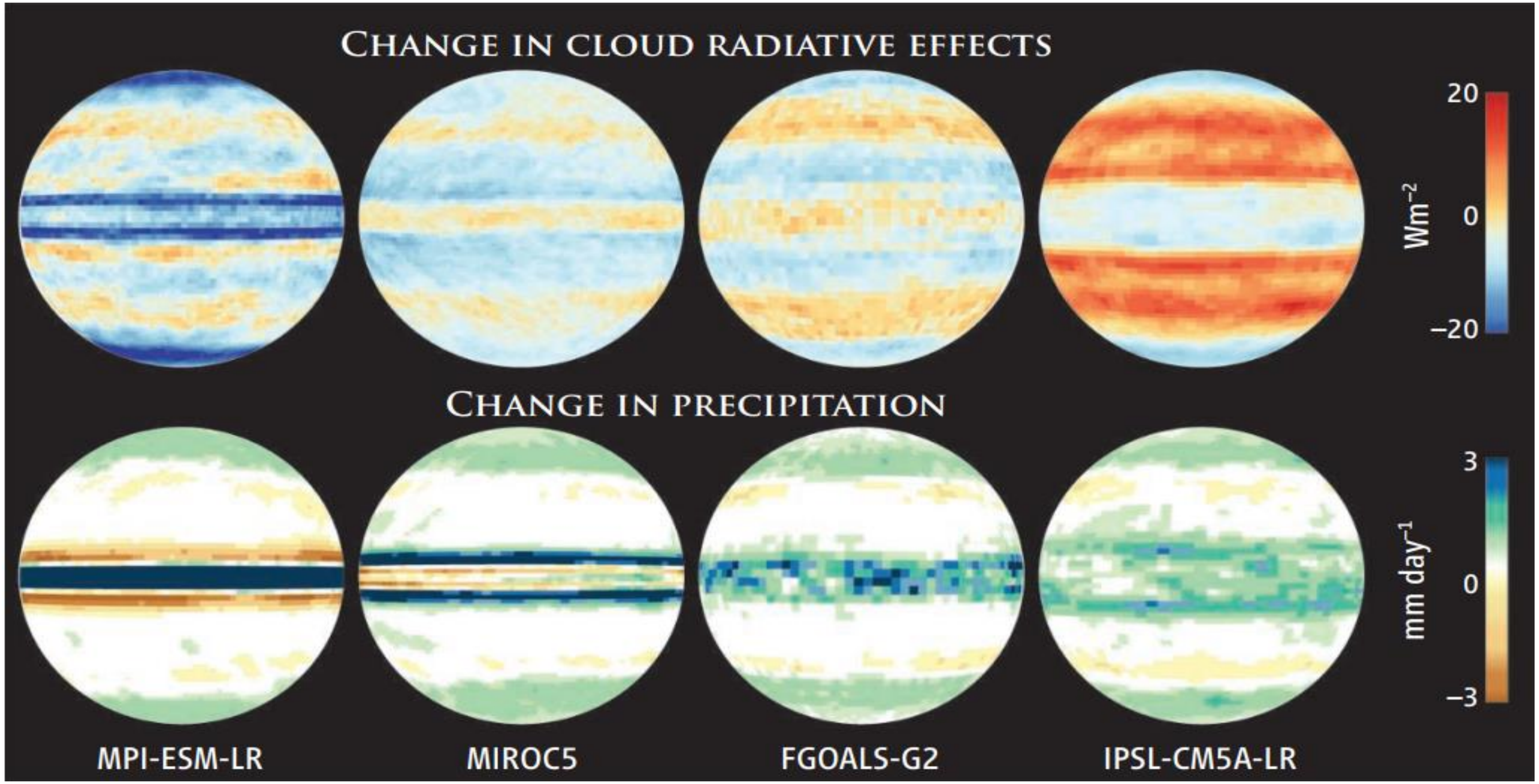
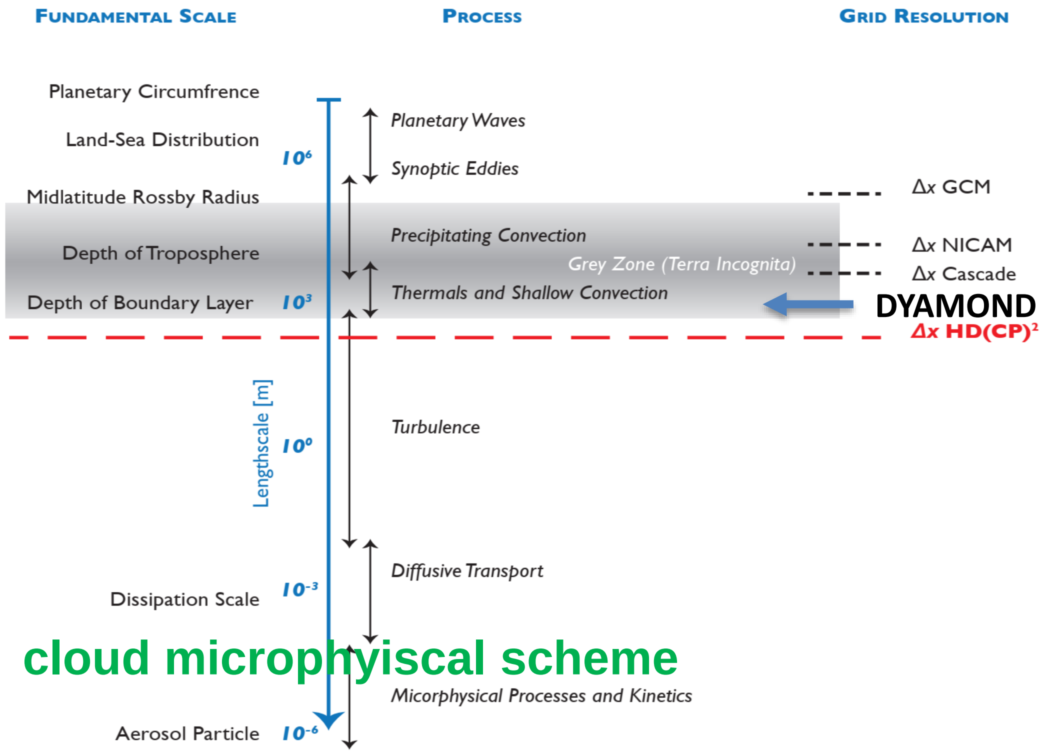
Aqua planet experiments with CMIP5 models



Stevens and Bony, 2013

CMIP5 models: response to climate change highly depends on the model (tropics) → **large uncertainties** in cloud processes

MOTIVATION



B. Stevens et al., 2011 HD(CP)2

Figure 2: Diagram showing fundamental scales and processes in the atmosphere and the grid spacing employed in state of the art modeling versus the grid spacing proposed for this project.

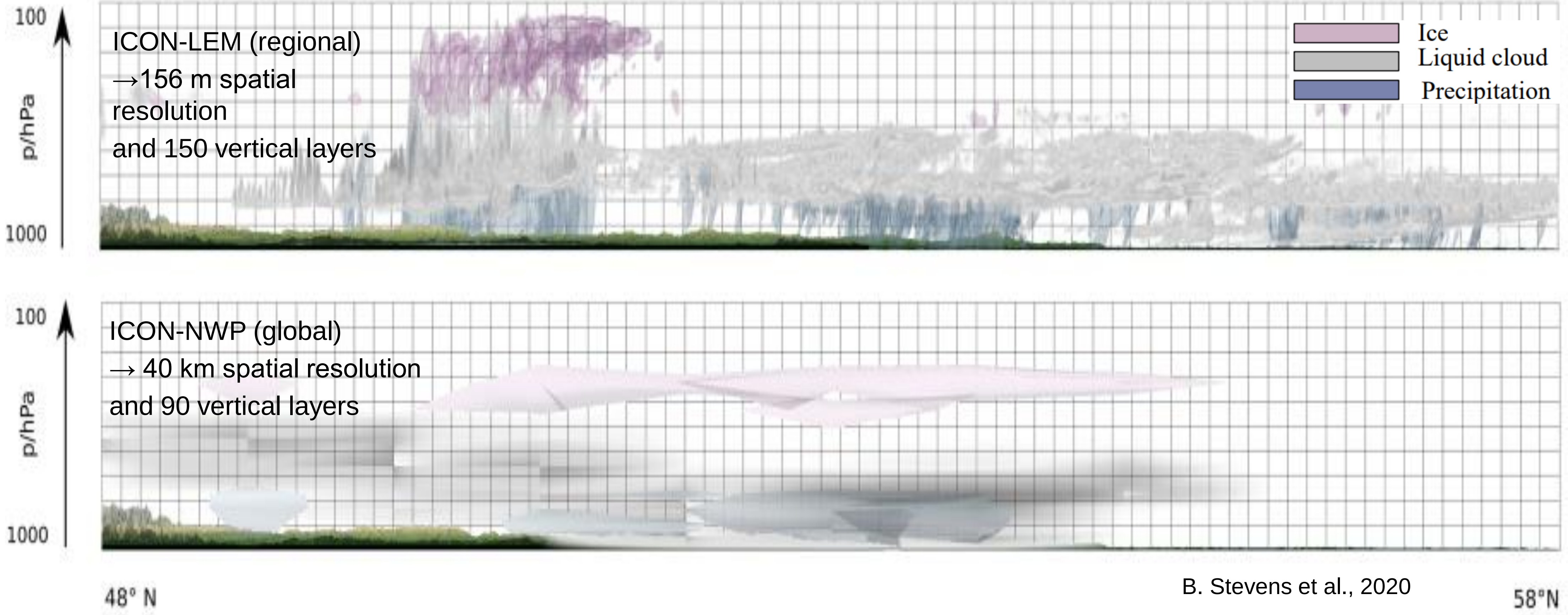
Cloud phase and **cloud vertical structure** are crucial to the **Earth's radiation budget** (Hong et al., 2016; Li et al., 2011; Liou, 1986; Matus and L'Ecuyer, 2017; Oreopoulos et al., 2017)

SRMs (**Grid spacing 5 km or less)** → mainly resolve deep convection

Water budget in the tropical UT is controlled by convection → Areas of interest: tropical convection

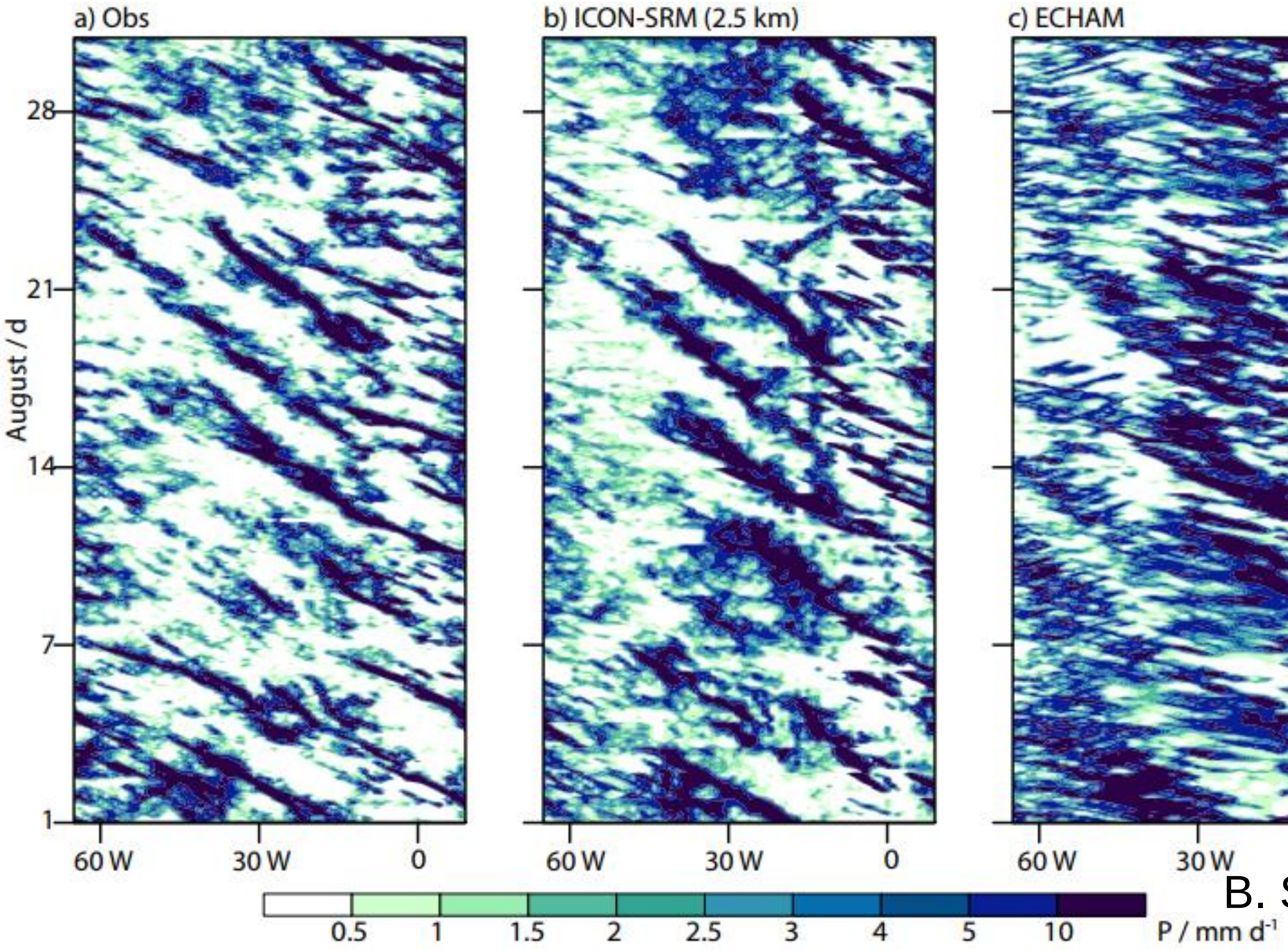
With deep convection mainly resolved,
how well is the tropical UT cloudiness simulated?

MOTIVATION



With deep convection mainly resolved,
how well is the tropical UT cloudiness simulated?

Storm-resolving models

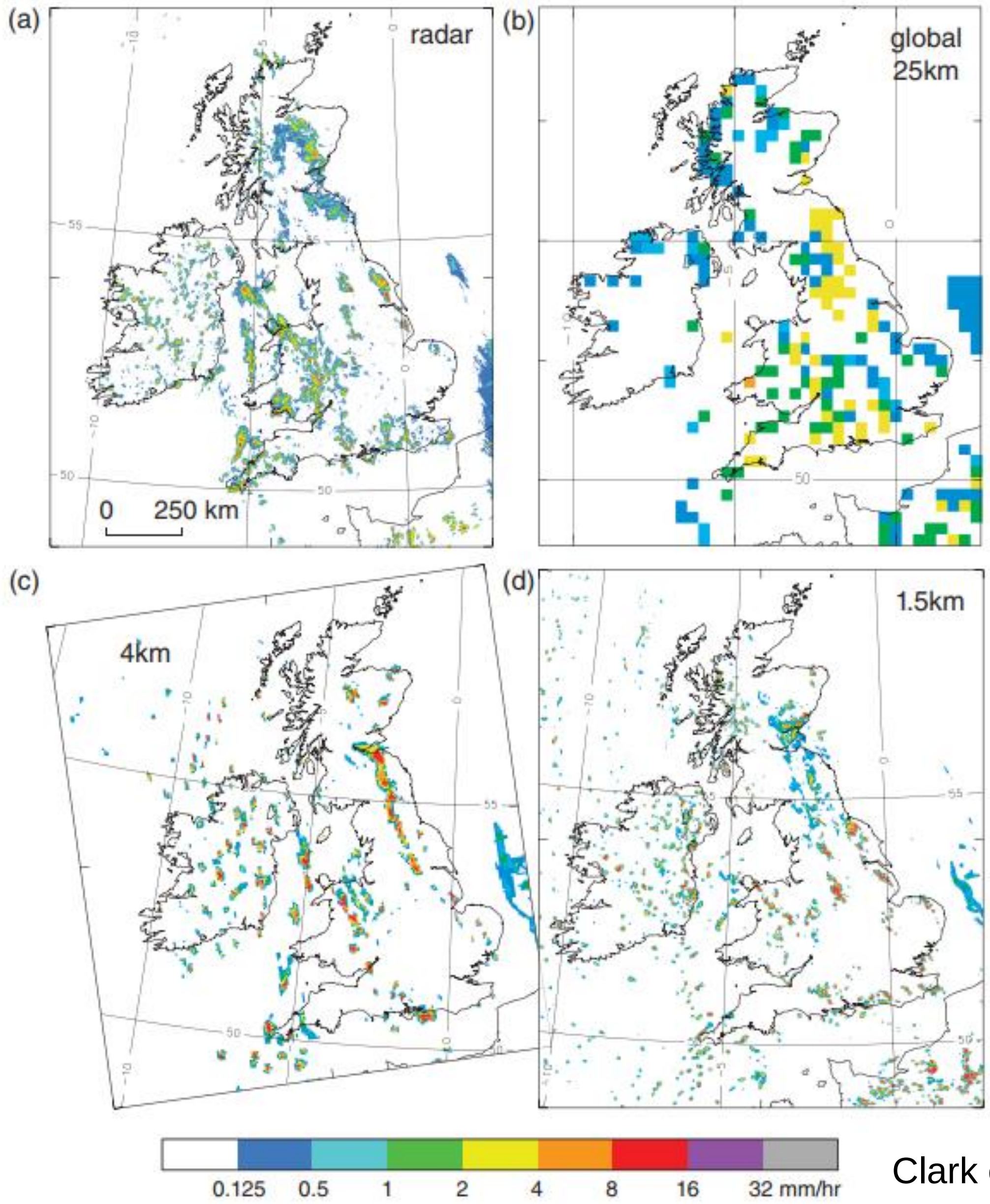


- SRMs → better representation of vertical velocities, clouds and precipitation (Stevens et al., 2020);
- Improvements in precipitation:
  - → better spatial distribution
  - → more realistic propagation of precipitating systems
  - → greatly improved daily cycle
- ECHAM → lack of large-scale propagating features & too strong daily cycle

B. Stevens et al., 2020

Hovmoeller plot of latitudinal averaged precipitation rate (2°S–16°N, mm d-1) over the tropical Atlantic during August 2016. Observations (IMERG) illustrated in a), ICON-SRM in b), and ECHAM c).

Convection permitting models benefits

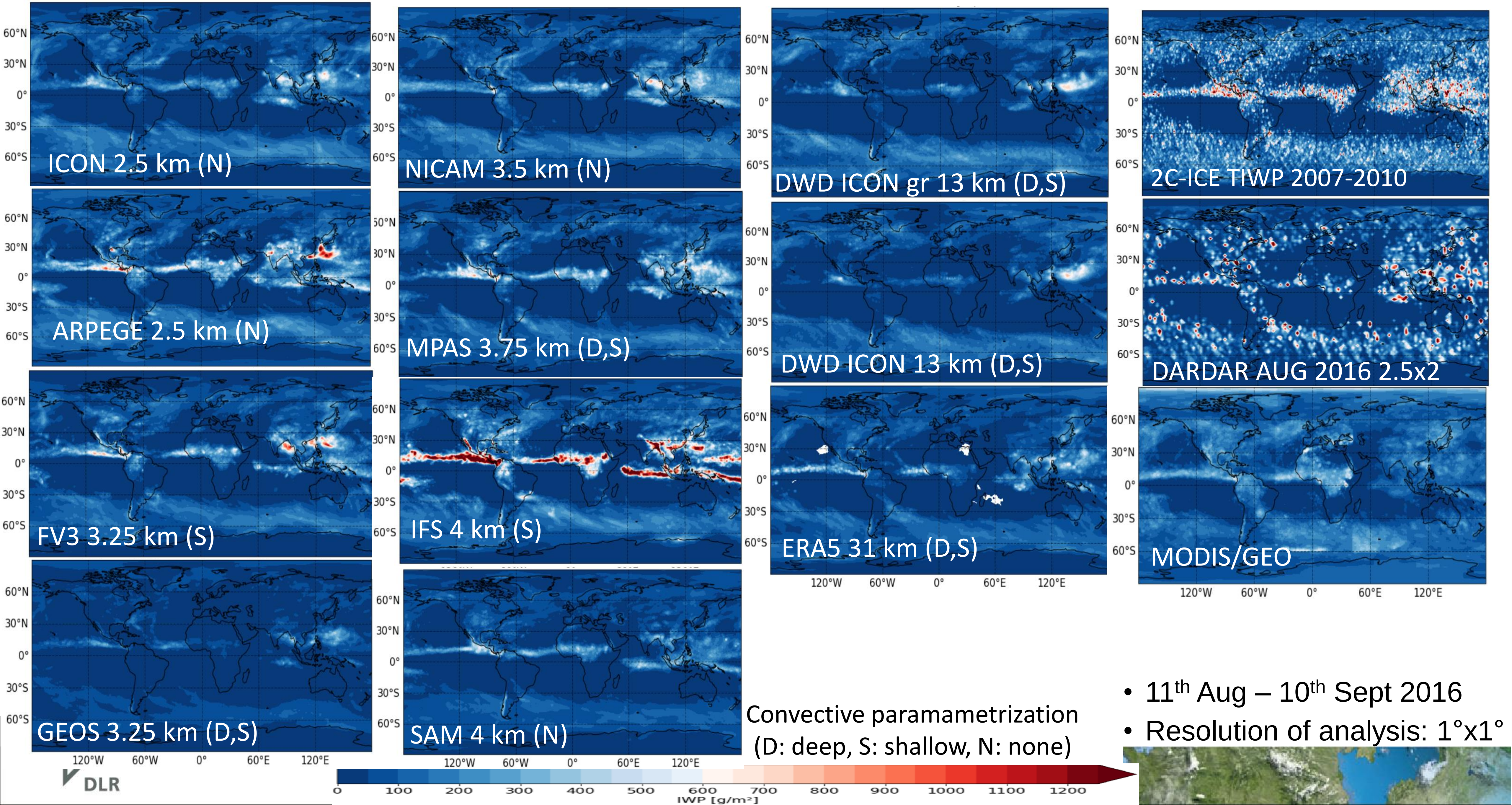


Clark et al 2016

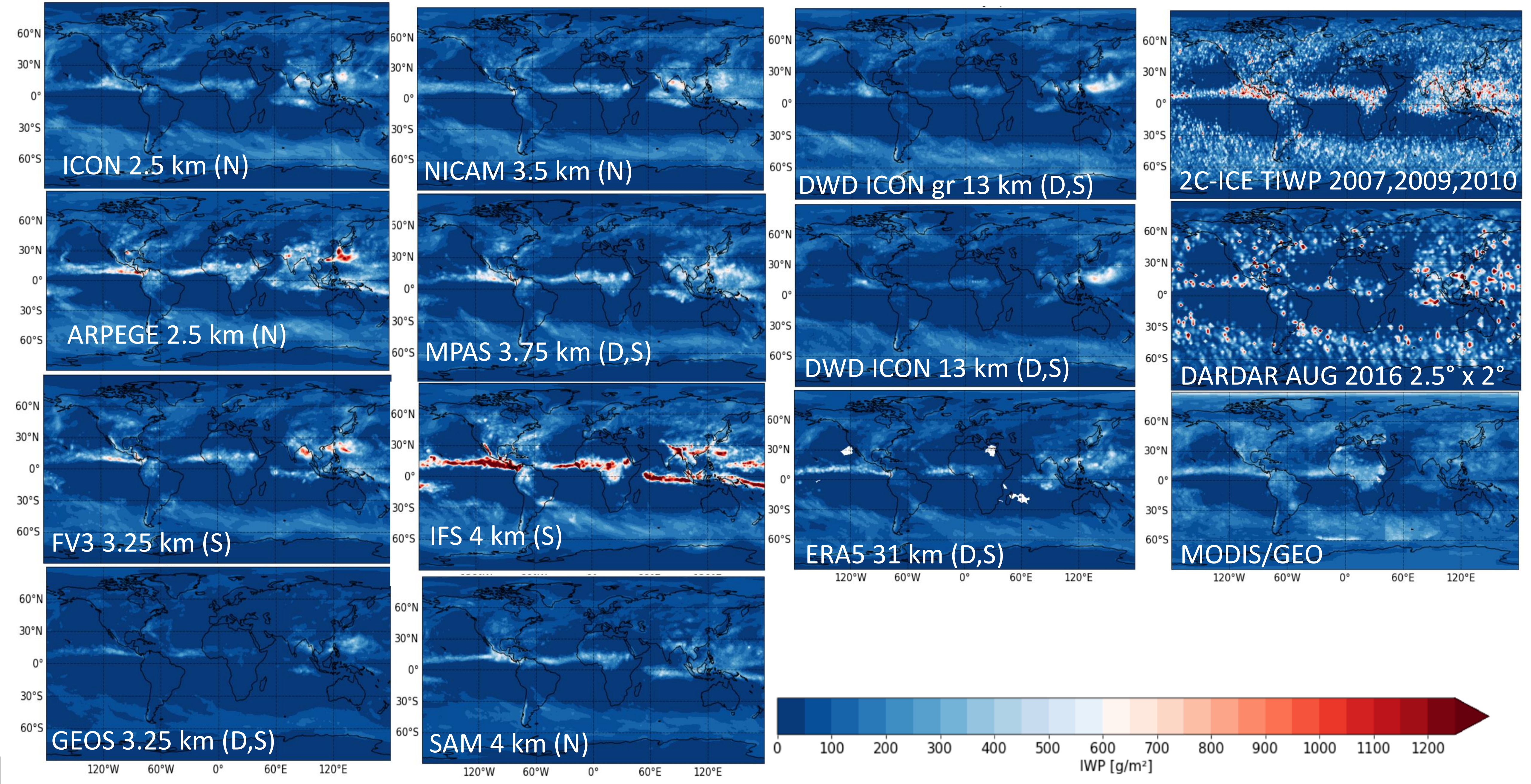
Case of convective showers over the UK on 8 July 2014 1200 UTC.

- “Step Change” in ability to forecast rainfall (Clark et al 2016)
- 25km (convection parametrized): little indication of organisation of rain and areas of heavy rain
- 4km: better at organised features but too much heavy rain and not enough light; features tend to be too large
- 1.5km: better scales in rainfall field (features smaller); better balance between heavy and light rain compared to radar
- Too much heavy rain, not enough light (appears to improve with increased resolution)

Total (ice + snow + graupel) ice water path (TIWP)

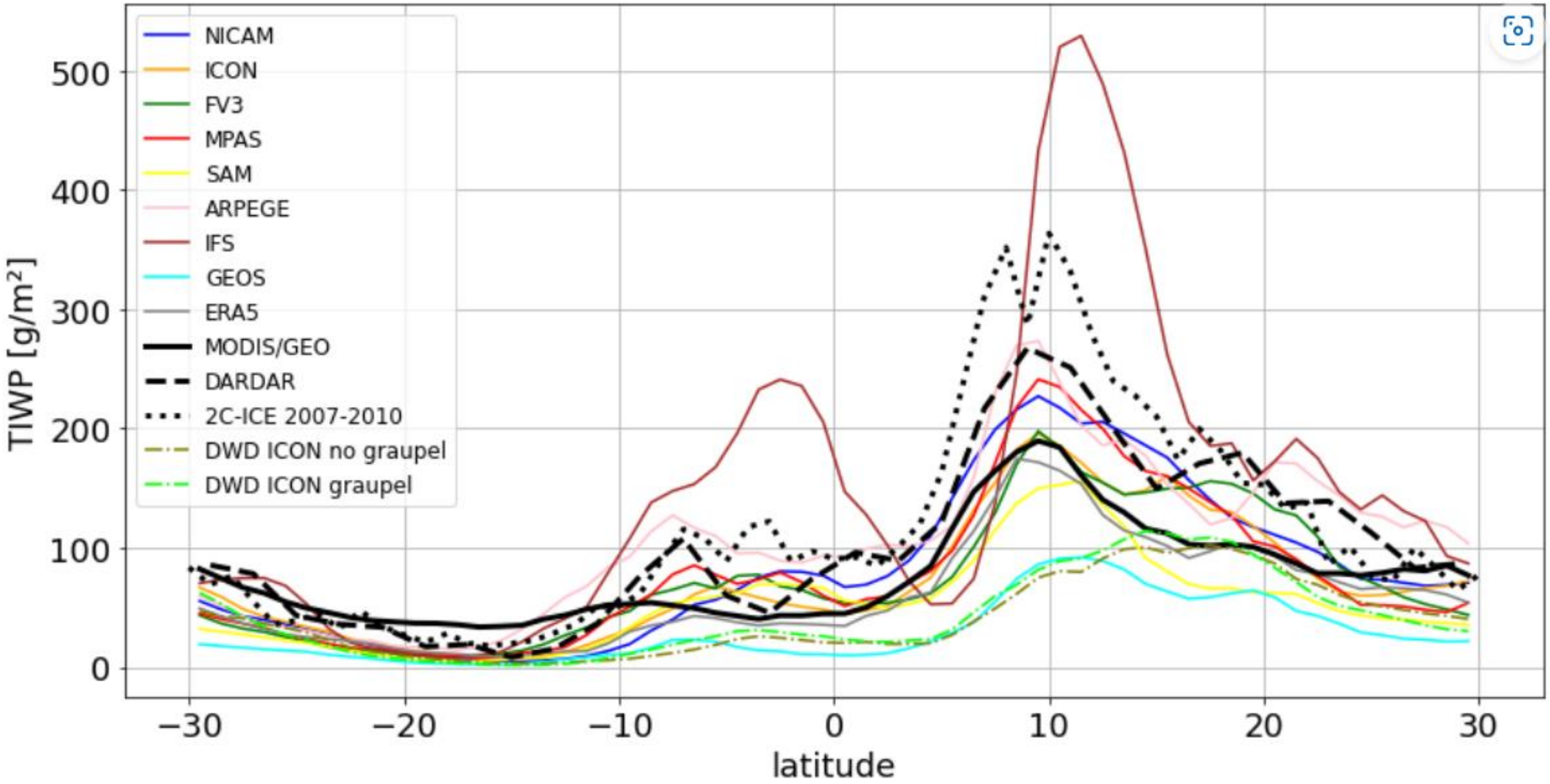


- 11^{th} Aug – 10^{th} Sept 2016
- Resolution of analysis: 1°x1°



ICON 2.5 km (N)
NICAM 3.5 km (N)
DWD ICON gr 13 km (D,S)
2C-ICE TIWP 2007,2009,2010
ARPEGE 2.5 km (N)
MPAS 3.75 km (D,S)
DWD ICON 13 km (D,S)
DARDAR AUG 2016 2.5° x 2°
FV3 3.25 km (S)
IFS 4 km (S)
ERA5 31 km (D,S)
MODIS/GEO
GEOS 3.25 km (D,S)
SAM 4 km (N)
60°N
30°N
0°
30°S
60°S
120°W
60°W
0°
60°E
120°E
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
IWP [g/m²]

Total (ice + snow + graupel) ice water path (TIWP) in high-resolution DYAMOND models



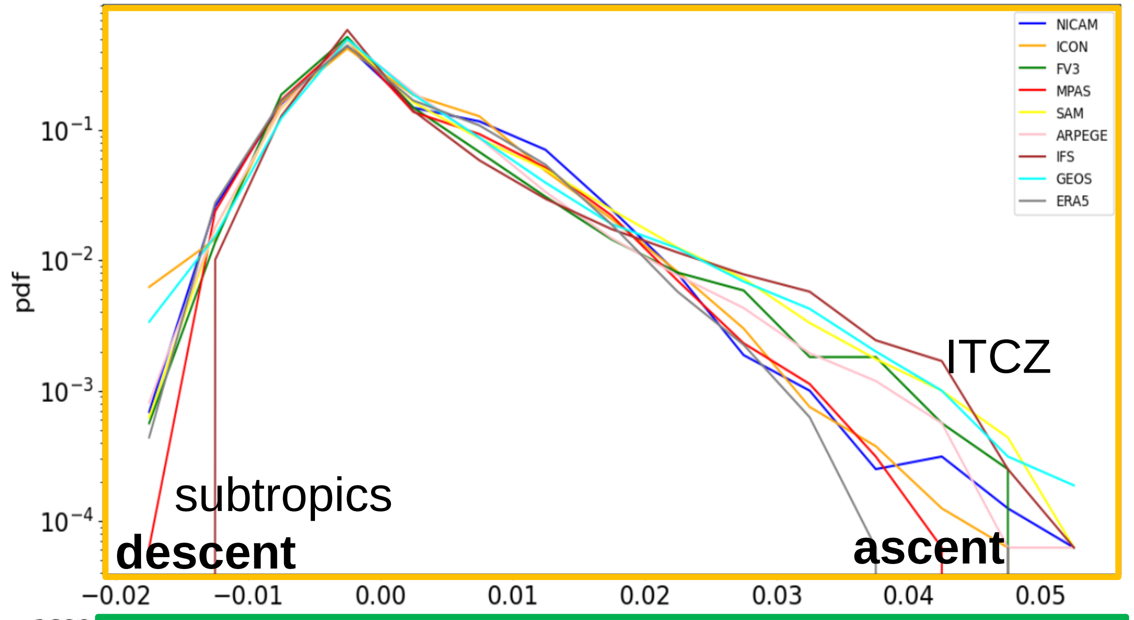
Tropical TIWP generally underestimated

Different TIWP distributions (too little IWP, maxima displaced) in NWP ICON

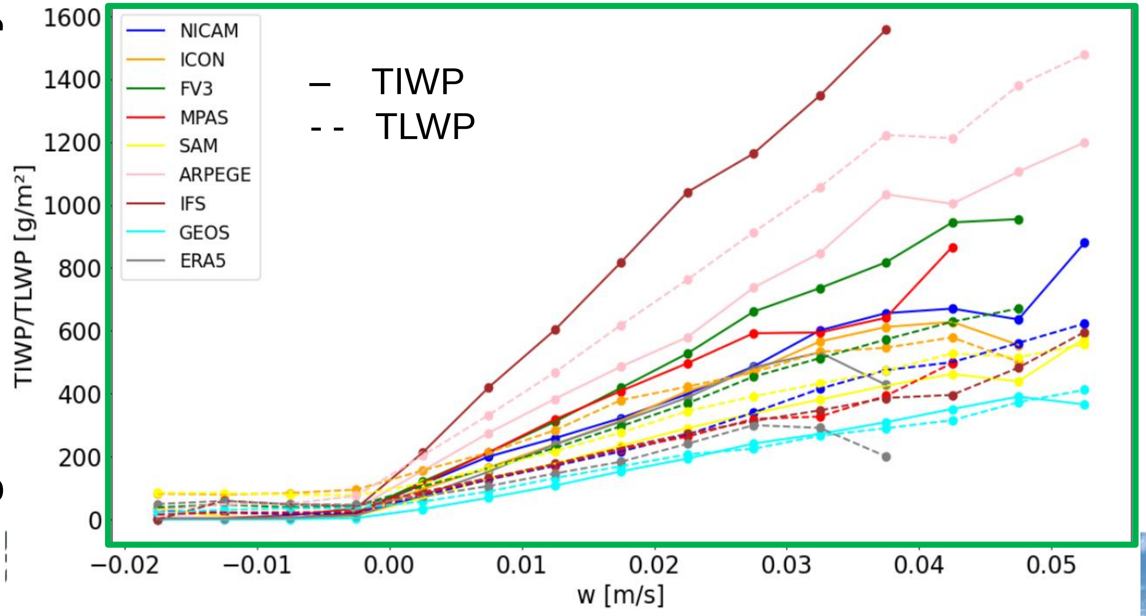
Is lack of TIWP in models due to dynamics or cloud scheme?

Monthly mean

PDF_w: indicator for the strength of convection



CWP_w: cloud water path for given vertical velocity



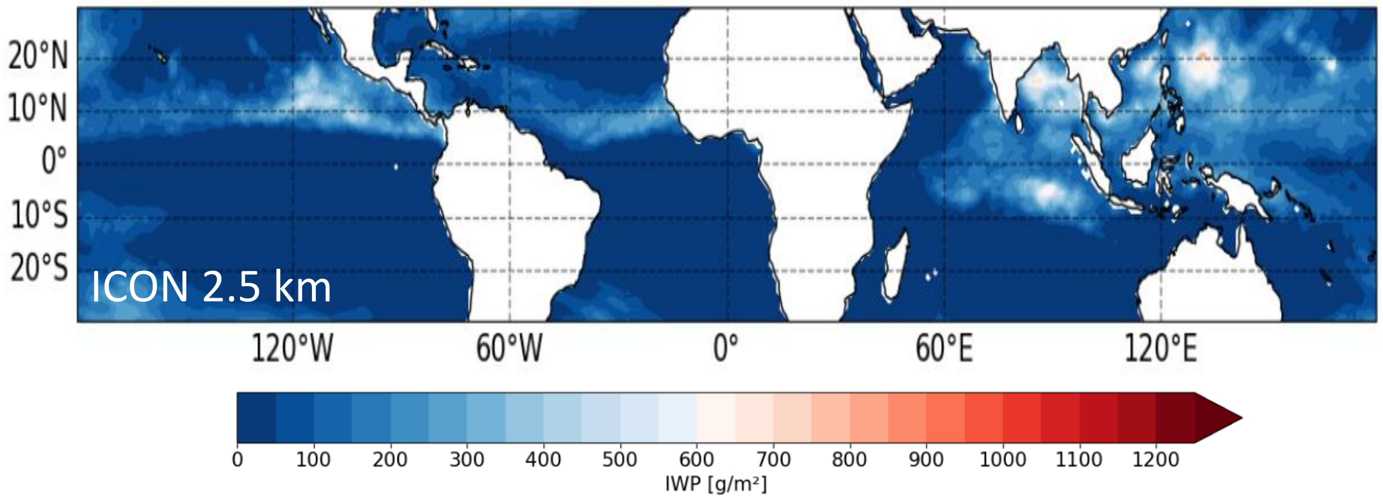
$$\overline{CWP} = \int_{-\infty}^{\infty} PDF_w \; CWP_w \; dw$$

CWP – Cloud water path
PDF_w – PDF of vertical velocity w (at 500 hPa);
CWP_w – Cloud water path for given vertical velocity

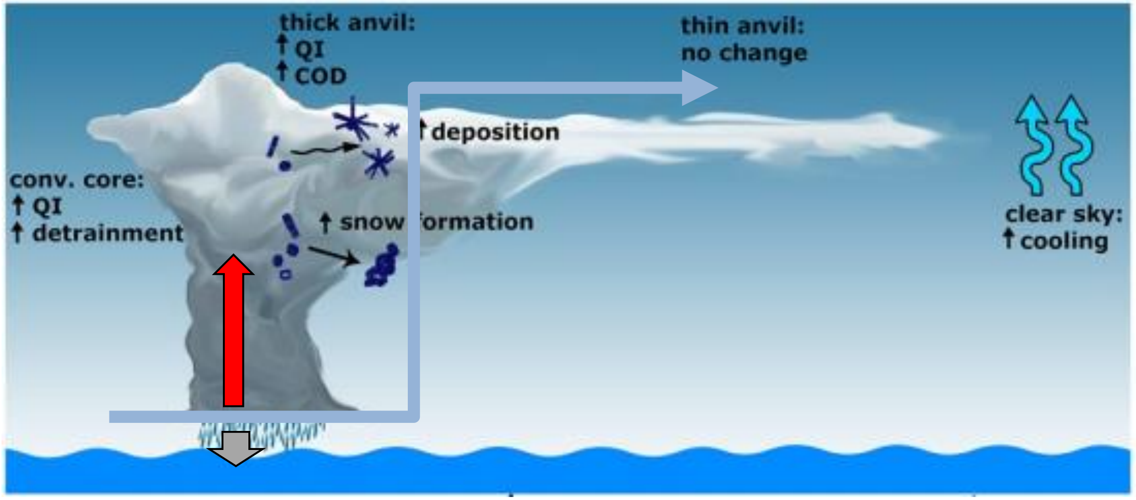
Large variability in cloud water path reaction to convection!

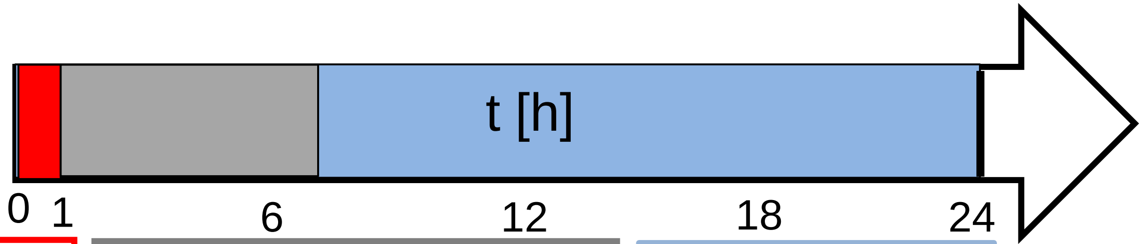
Time scales of analysis

Monthly mean



Daily mean





Climate time scale

Updraft time scale

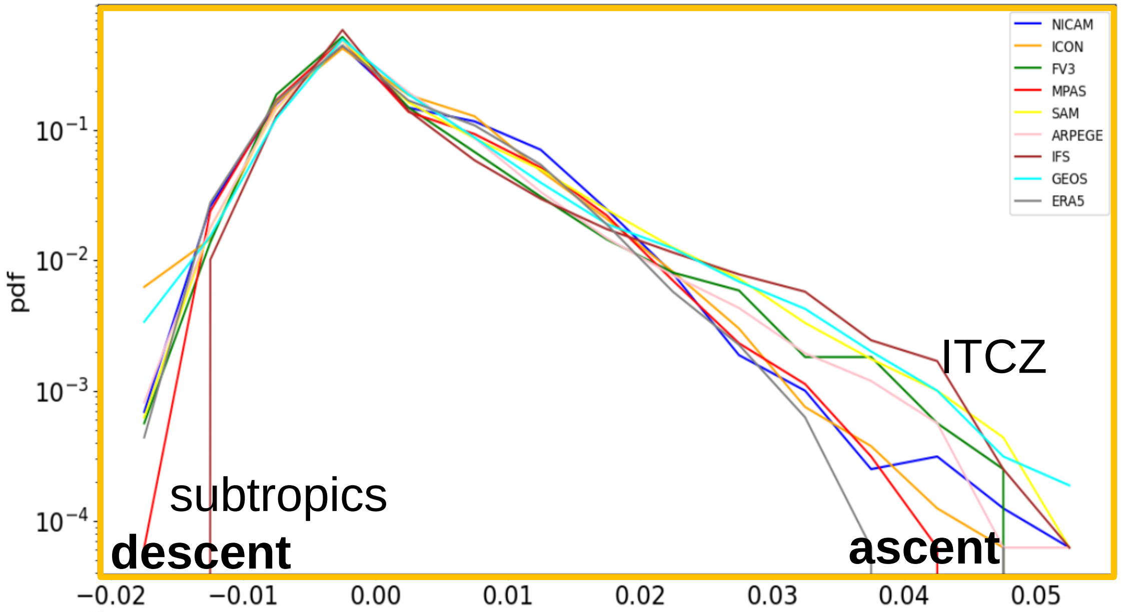
Precipitation time scale

Anvil time scale

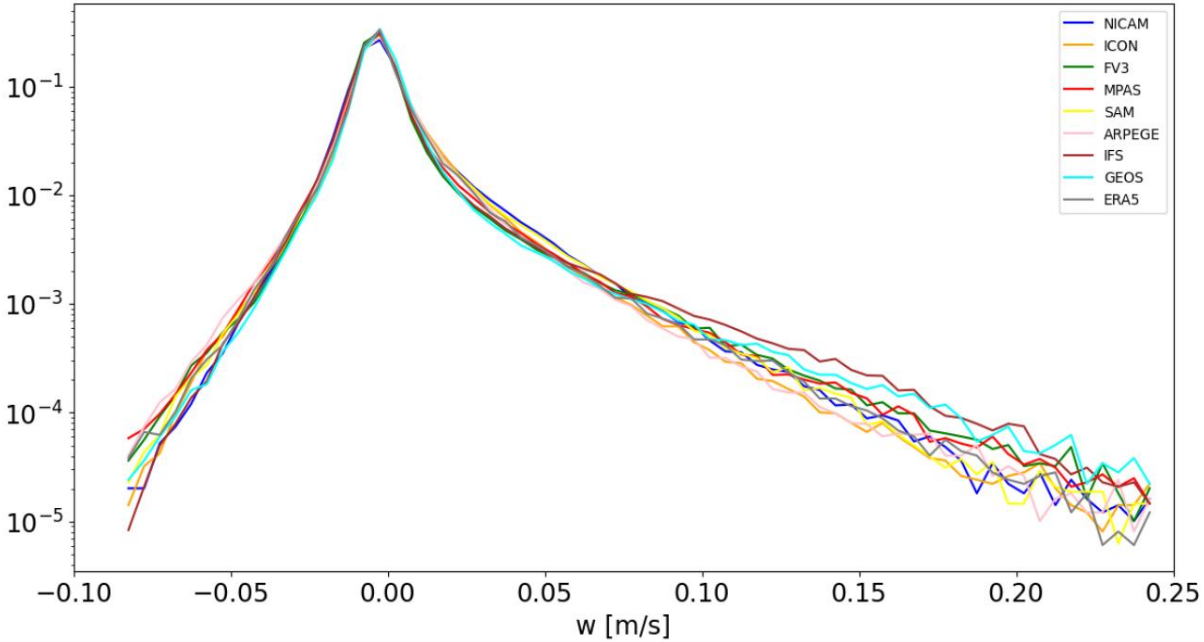
How different is dynamics between the high-resolution models?

Monthly mean

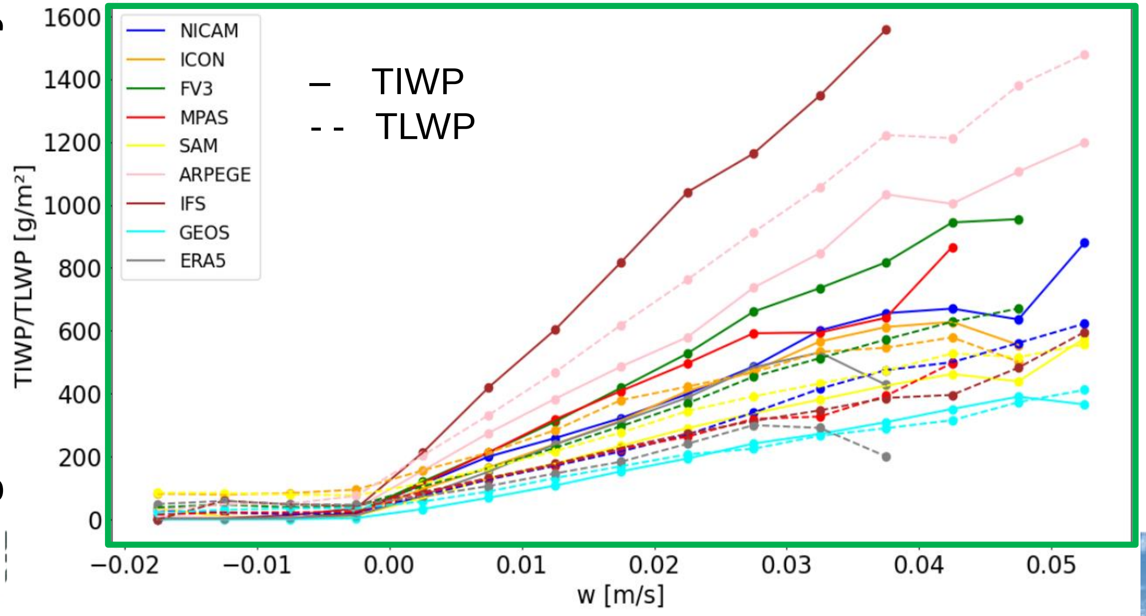
PDF$_w$: indicator for the strength of convection



Daily mean



CWP$_w$:cloud water path for given vertical velocity



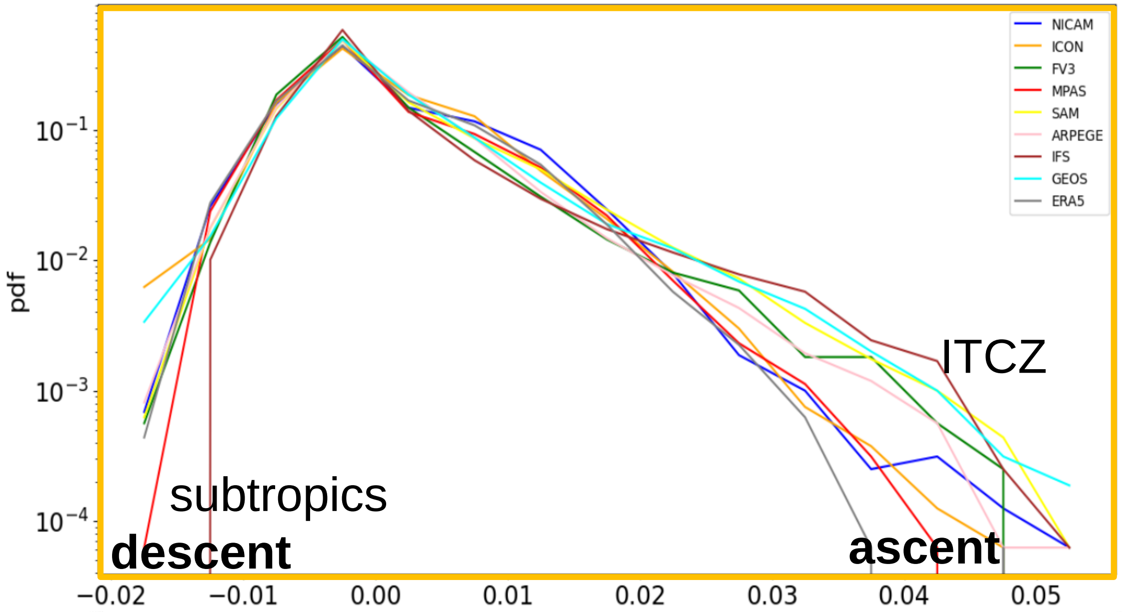
→ Models exhibit similar convective activity on anvil time scales

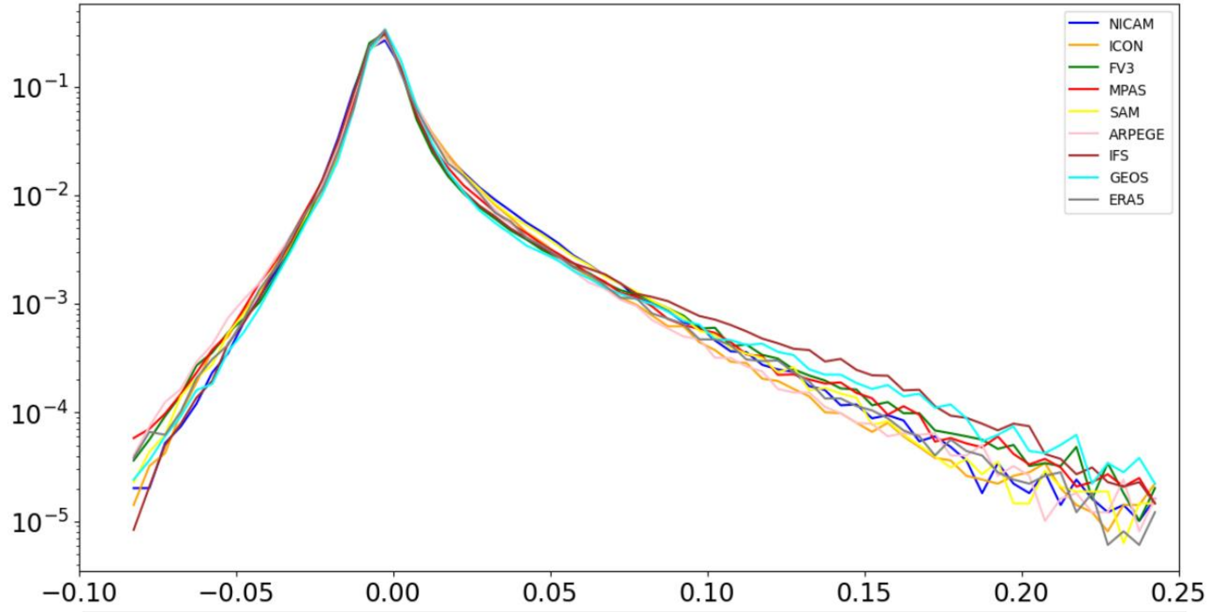
→ Differences in spatial distribution (scattered in ERA5)

Impact of convection on UT cloudiness varies strongly!

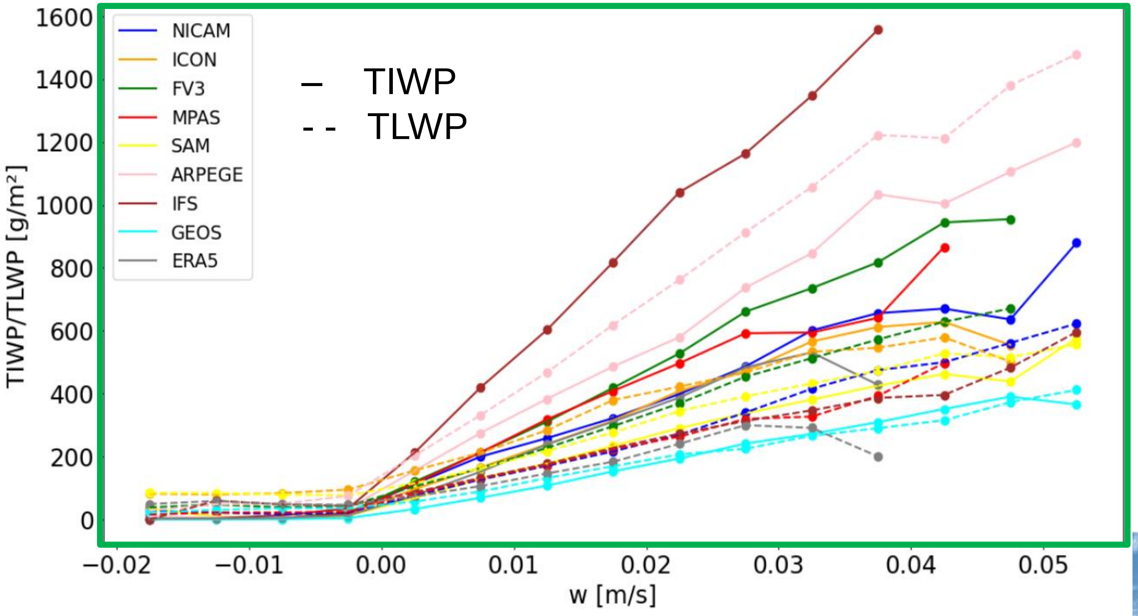
Monthly mean | Daily mean

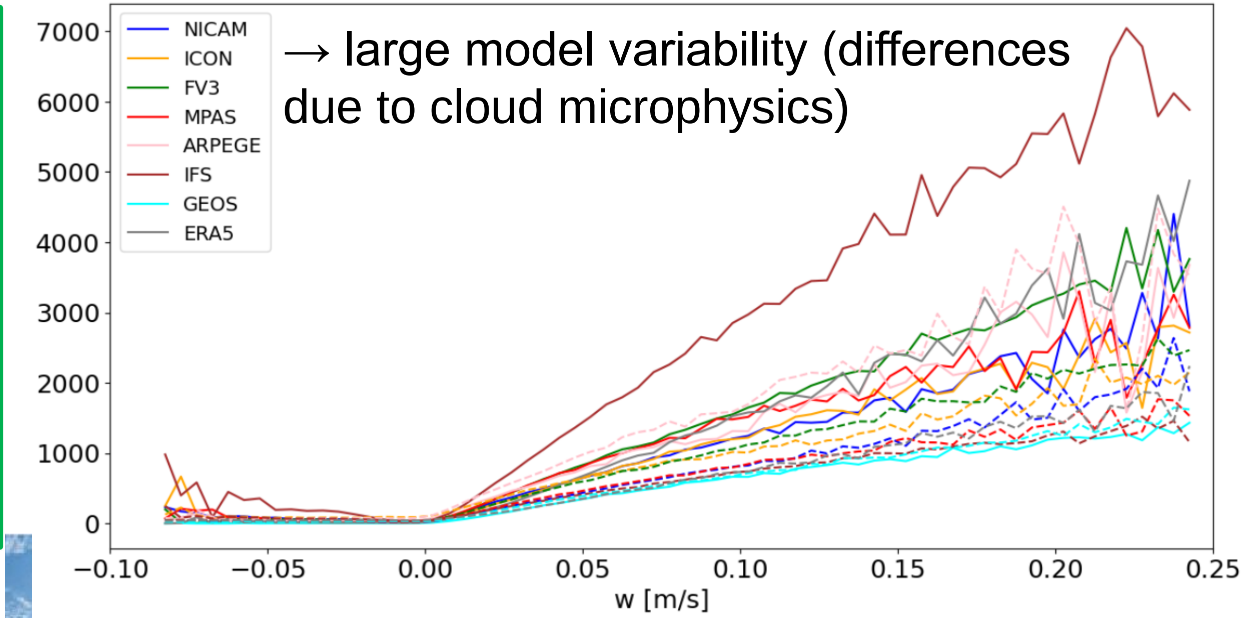
PDF_w: indicator for the strength of convection





CWP_w: cloud water path for given vertical velocity



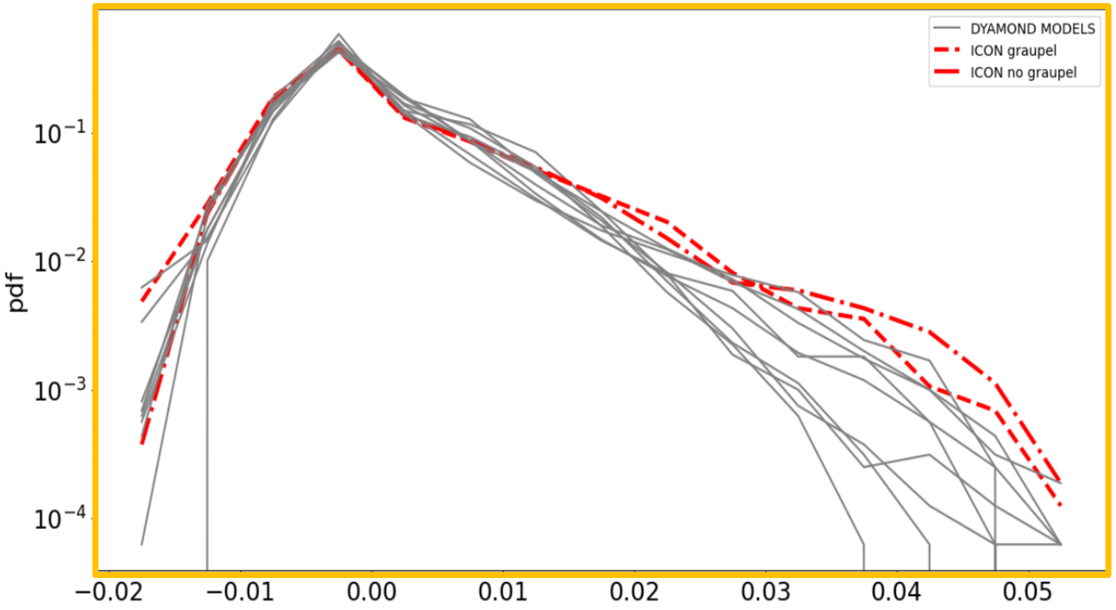


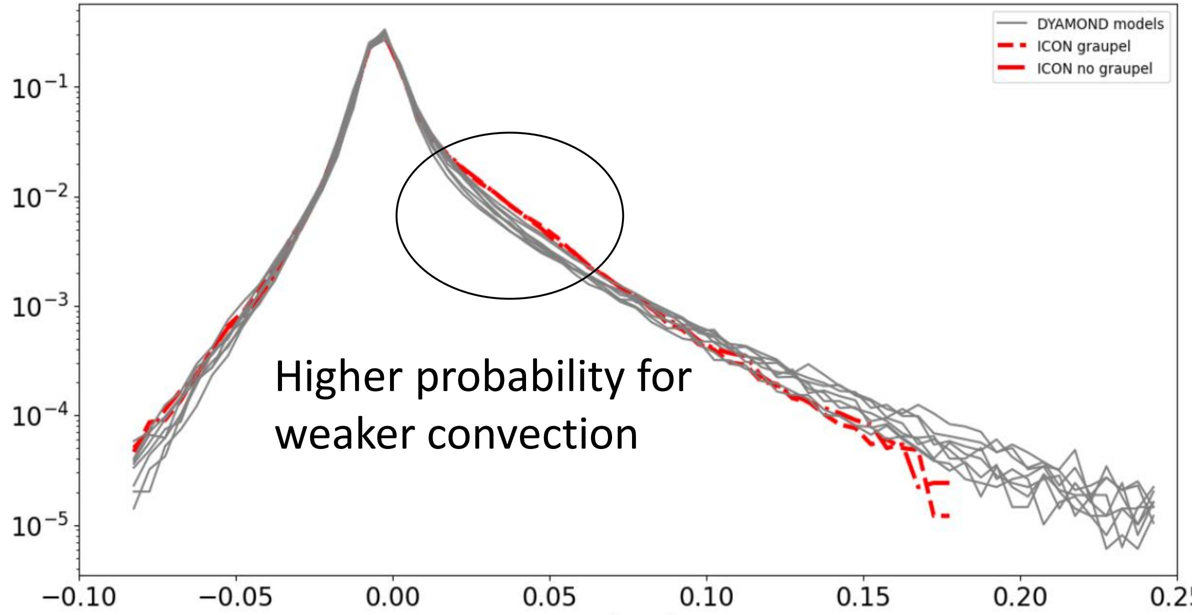
How different are NWP models compared to high-resolution models?

Monthly mean

Daily mean

PDF_w: indicator for the strength of convection





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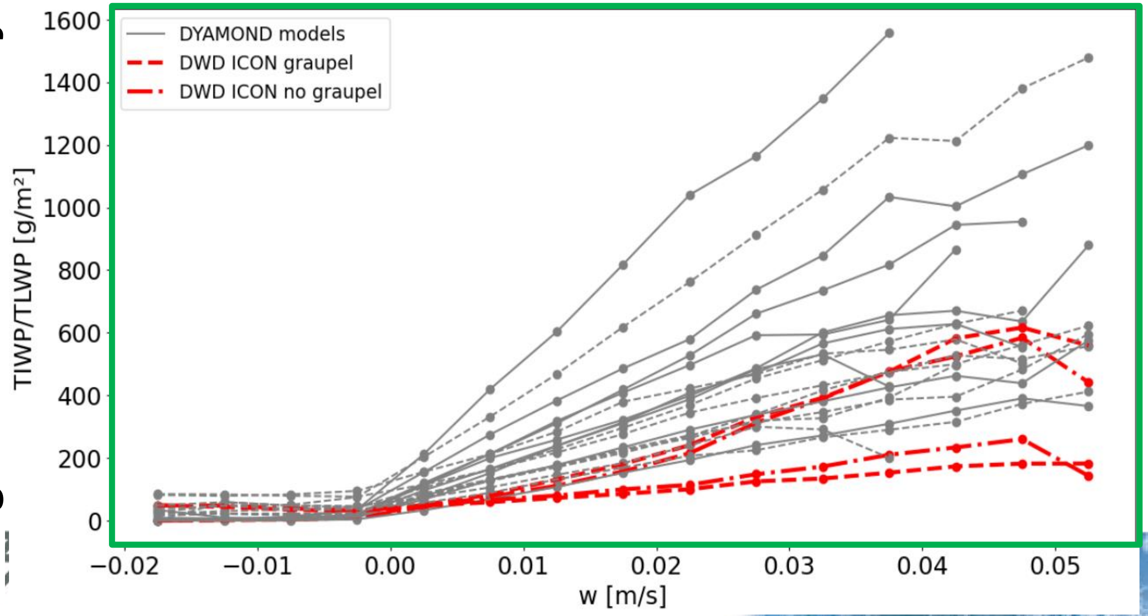
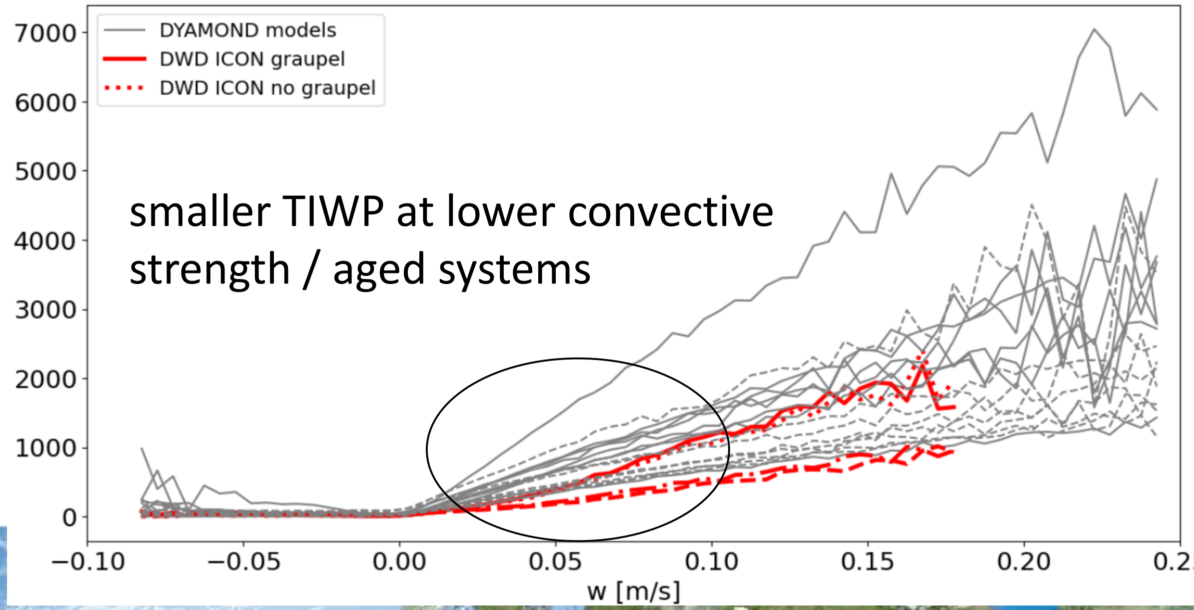




Is lack of TIWP in models due to dynamics or cloud scheme?

$$\overline{CWP} = \int_{-\infty}^{\infty} PDF_w \; CWP_w \; dw$$

CWP – Cloud water path
PDF_w – PDF of vertical velocity w (at 500 hPa);
CWP_w – Cloud water path for given vertical velocity

MM = multi-model mean
IM = individual-model

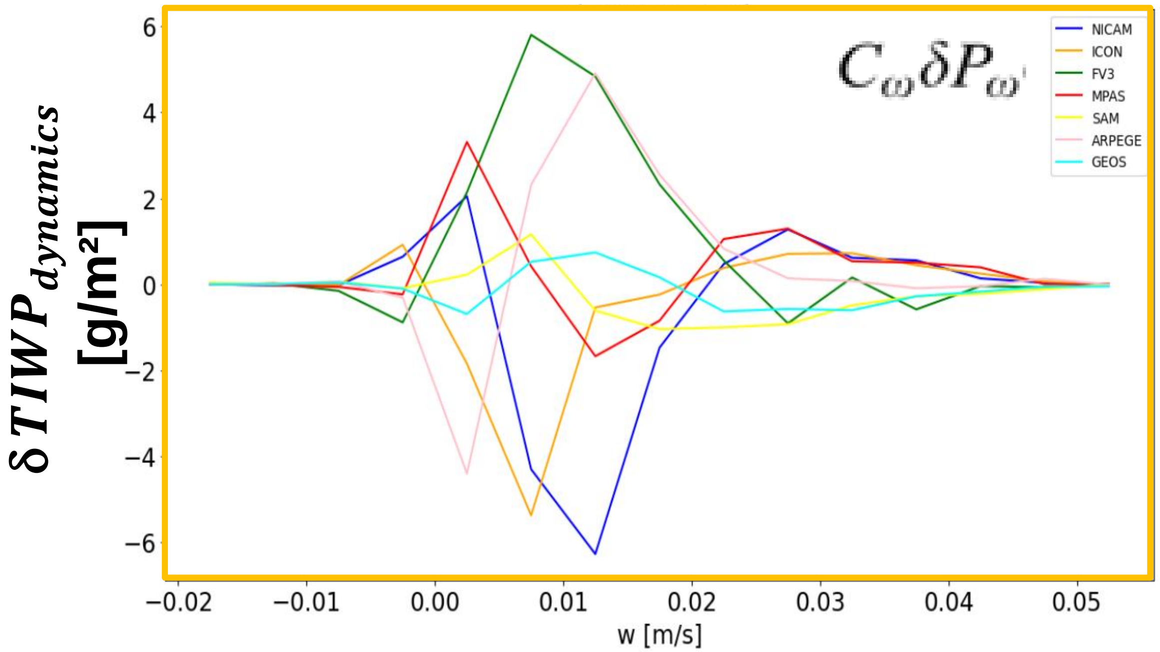
$$\delta TIWP_{dynamics} = TIWP_w \text{ (IM)} * PDF_w \text{ (MM)} - TIWP_w \text{ (IM)} * PDF_w \text{ (IM)}$$

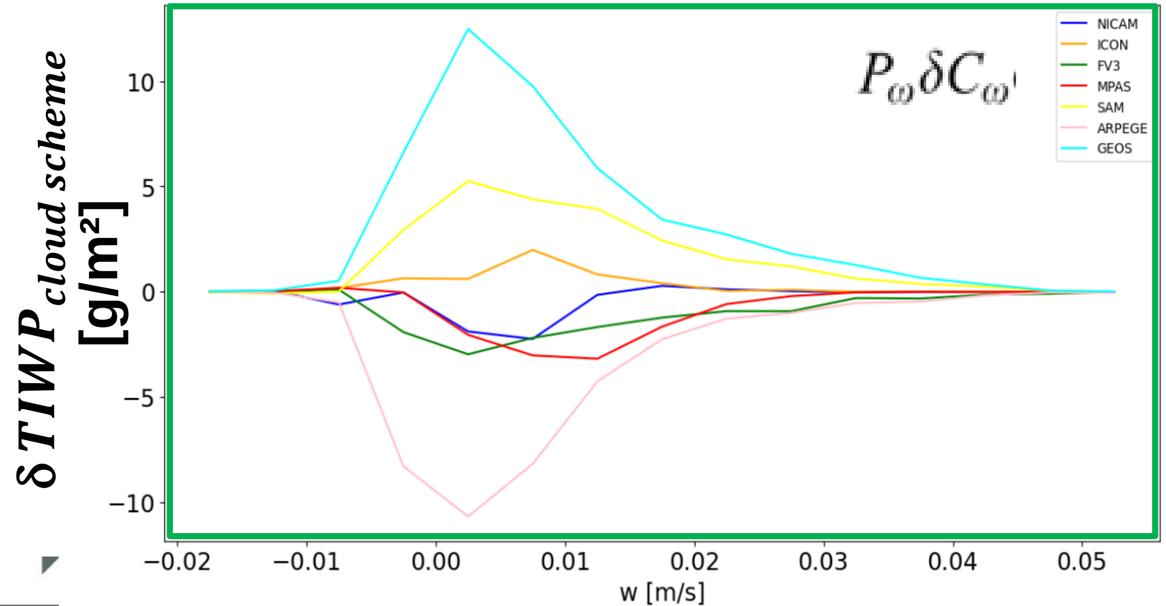
$$\delta TIWP_{cloud\ scheme} = PDF_w \text{ (IM)} * TIWP_w \text{ (MM)} - PDF_w \text{ (IM)} * TIWP_w \text{ (IM)}$$

DLR

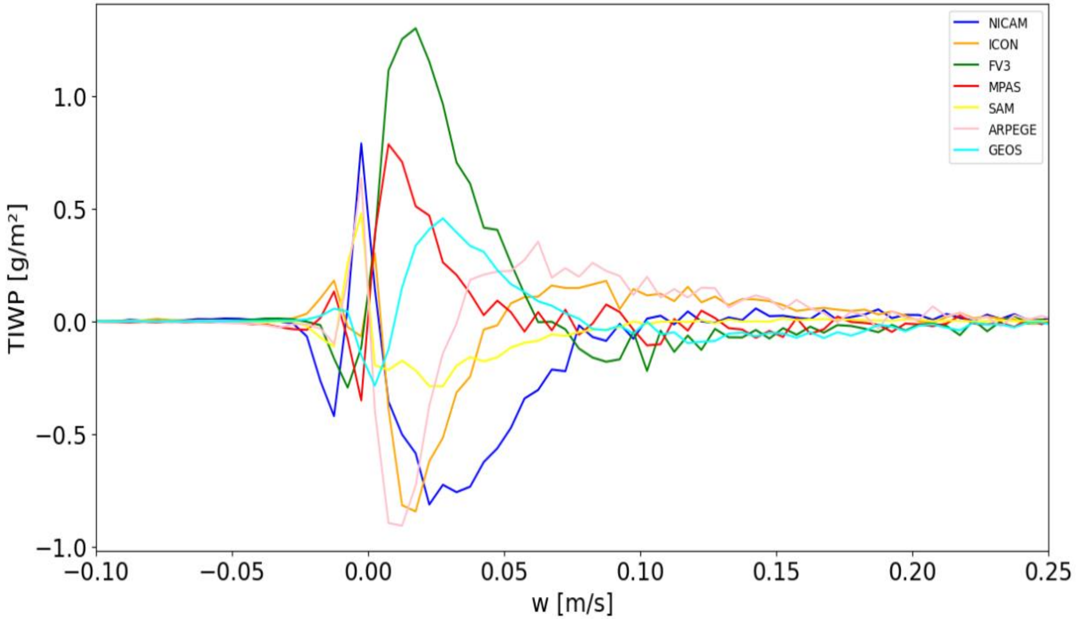
Is lack of TIWP in models due to dynamics or cloud scheme?

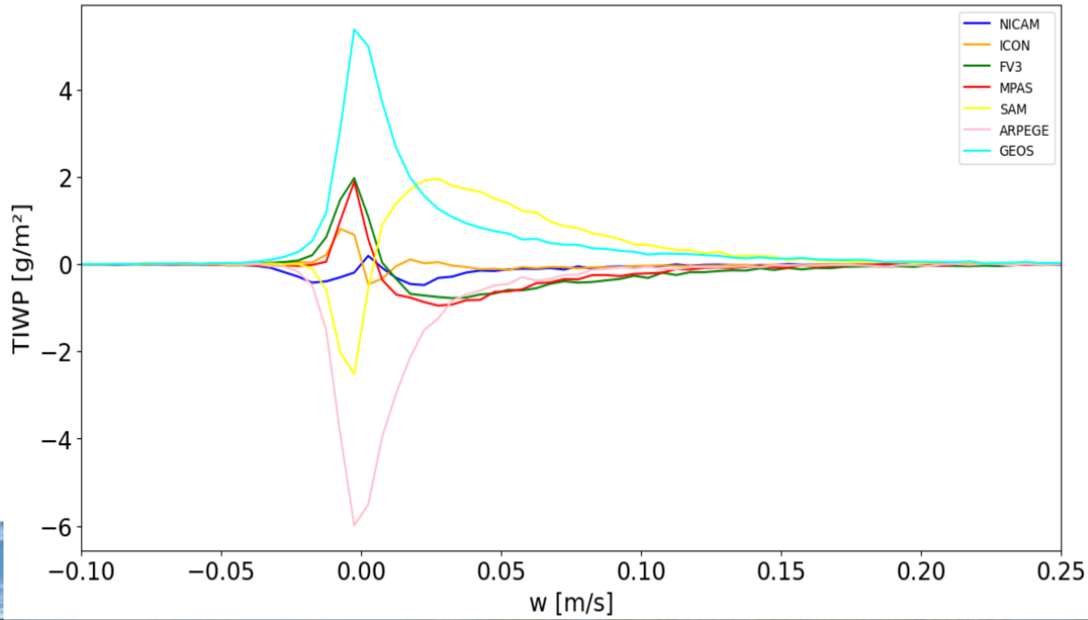
Monthly mean



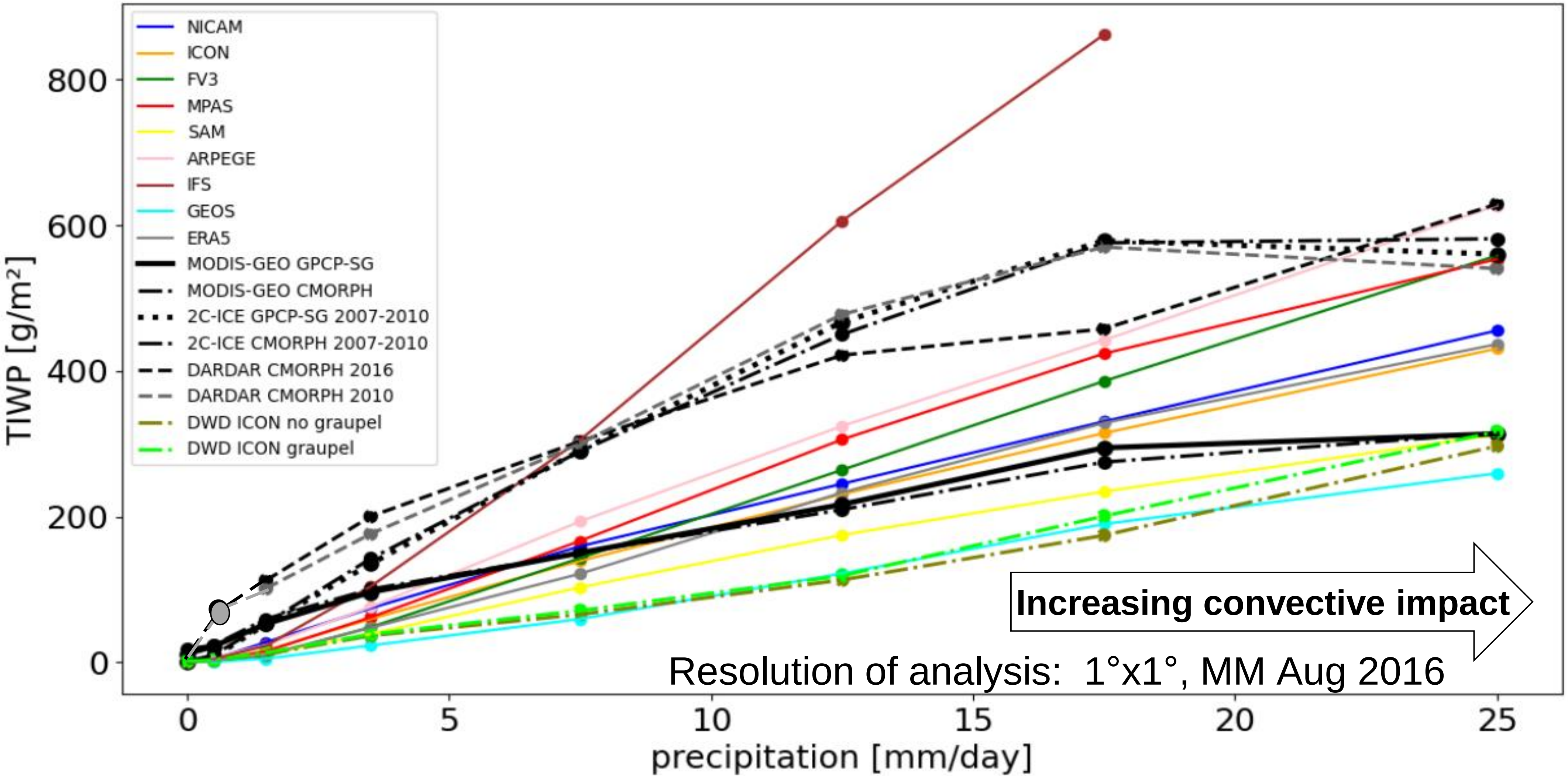


Daily mean





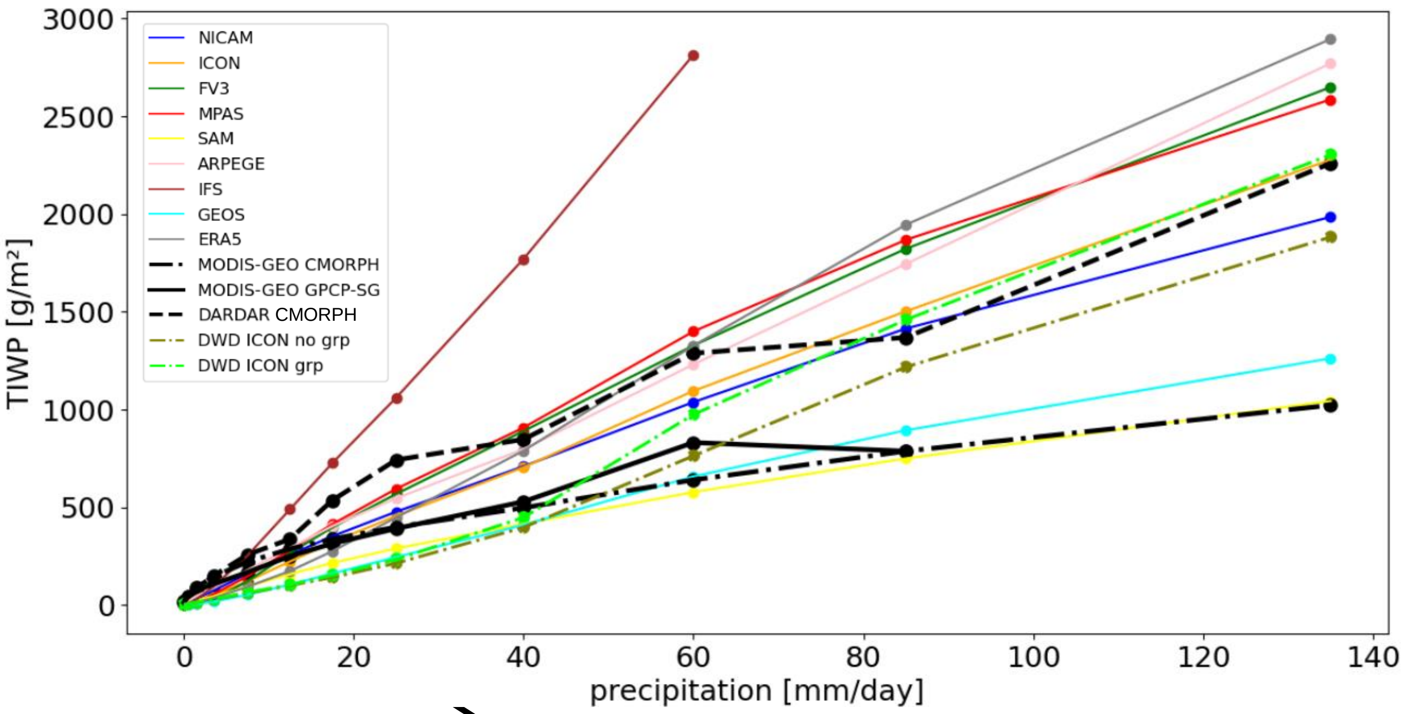
Monthly partitioning of TIWP / precipitation (Tropical ocean)



TIWP generally underestimated (compared to active remote sensing)

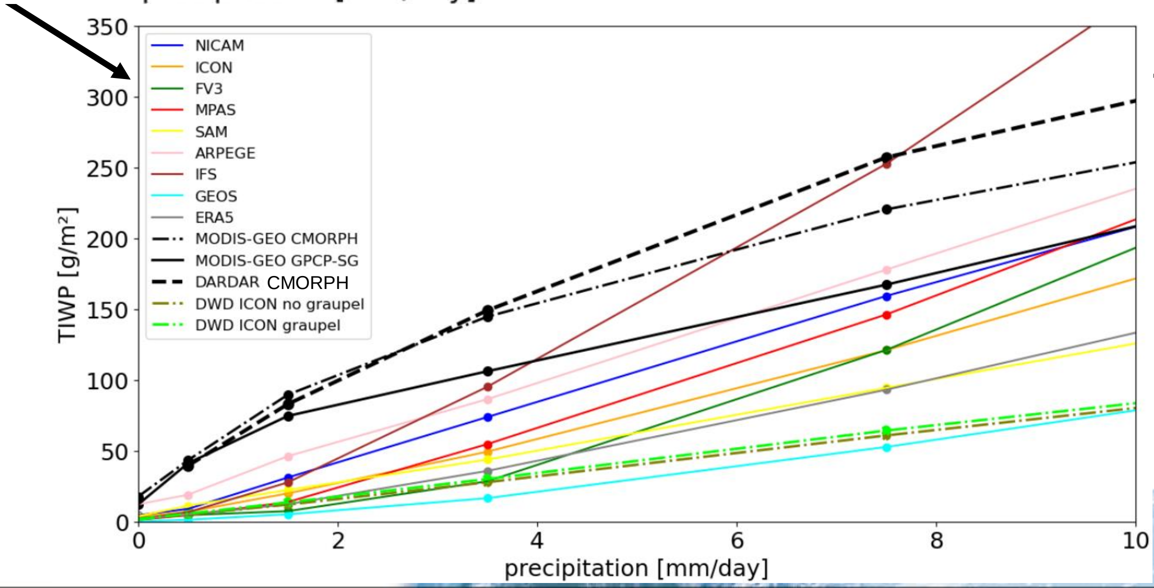
In very low precipitation areas, TIWP underestimated even relative to passive rms

Daily partitioning of TIWP / precipitation (Tropical Ocean)



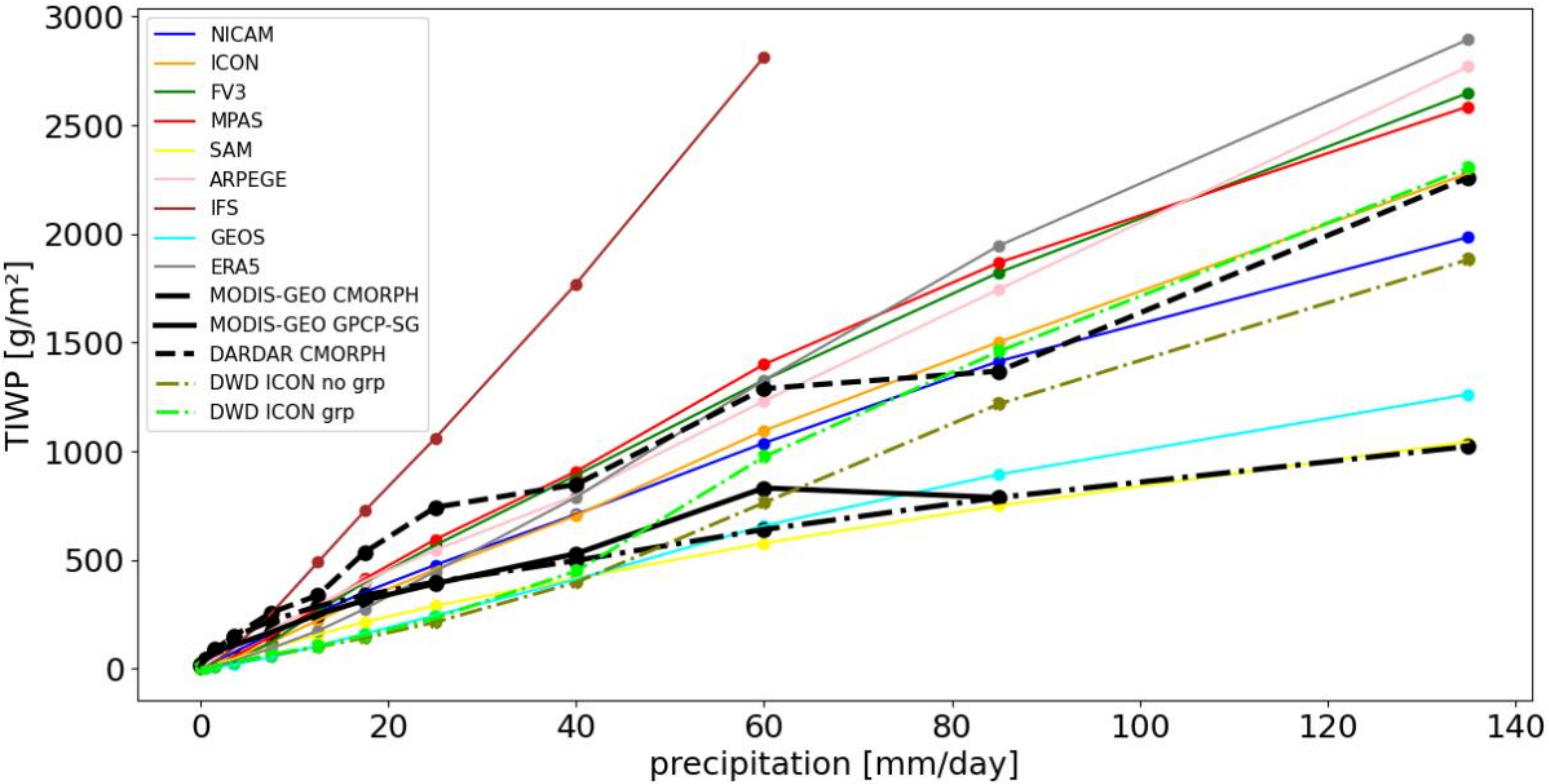
TIWP is generally underestimated (especially at lower convective strength (compared to active remote sensing) but improved compared to ICON-NWP

Passive remote sensing shows saturation in areas of high IWP



TIWP underestimated in very low precipitation areas even relative to passive remote sensing!

Resolution of analysis: 1°x1°, 11th Aug – 11th Sept



TIWP [g/m²]
3000
2500
2000
1500
1000
500
0
0
20
40
60
80
100
120
140
precipitation [mm/day]
NICAM
ICON
FV3
MPAS
SAM
ARPEGE
IFS
GEOS
ERA5
MODIS-GEO CMORPH
MODIS-GEO GPCP-SG
DARDAR CMORPH
DWD ICON no grp
DWD ICON grp

Can high resolution models reliably simulate cloudiness originating from convection?

Cloud scale dynamics is much **improved** in the high-resolution simulations but **TIWP** significantly **underestimated**

Different SRMs show large variability in cloud water path response to vertical velocity

Overall underestimation in TIWP is mainly caused by model‘s cloud scheme

Comparison with observations shows:
Underestimation of TIWP in SRMs is largely caused by underestimating TIWP of **weaker and/or aged convective systems** while strong and young convective systems are simulated well

In **NWP model** (13km resolution) **underestimation** of **TIWP** is **more pronounced in weaker and/or aged convective systems**

⇨ **Double moment microphysics** may lead to improvements in simulated convective life cycles

New data sets, such as those coming from Earthcare or initiatives learning from lidar, radar and in-situ measurements, may help advance cloud schemes in the near future

THANK YOU