

Using EarthCARE to improve the treatment of clouds, precipitation and radiation in the ICON model

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Motivation

Goal of current work:

- Make use of EarthCARE for model development at DWD.
- Get to know EarthCARE data and products.

Specific task:

- Compare EarthCARE radiative fluxes with CERES products.
- Use EarthCARE ACM-GAP products to validate clouds in ICON.
- Compare one-moment and two-moment cloud ice representation with EarthCARE data.

EarthCARE radiative flux data

- BBR L2b data for July 2025 as downloaded from OADS
- ECA_EXBA_BMA_FLX files from 6193G to 6660D (1-30 July 2025)
- Specifically, solar_comb_toa_flux and thermal_comb_toa_flux.
- Nearest neighbor mapping to ICON grid on model time step of 120 s
- Only BBR data with quality_status=0 (both fluxes are fully trustful)

CERES radiative flux data

CERES SSF:

- CERES SSF L2 data from LARC
- NOAA20-FM6-E1C, Terra-FM1-E4A, Aqua-FM3-E4A
- Nearest neighbor mapping to ICON grid on 20 min ICON output.

CERES SYN1DEG:

- CERES SYN1DEG L3 data from LARC.
- Combines geostationary satellites with all available CERES instruments.
- Hourly data with full global coverage but only 1 degree spatial resolution.
- Conservative remapping of hourly ICON data to 1 degree global grid.

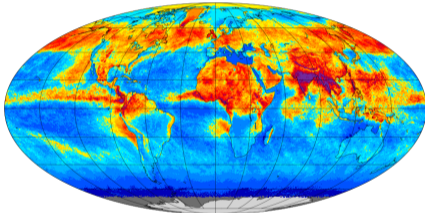
ICON model configuration

- Global R03B07 (12 km) icosahedral grid with 120 levels
- Daily 00 UTC forecasts of July 2025 using 6-30 h of each day.
- ecRad radiation with Tegen aerosol climatology.
- Tiedtke-Bechtold convection scheme similar to ECMWF's IFS.
- Two-moment cloud ice microphysics scheme.
- Coupling with ecRad radiation through consistent effective radius from two-moment cloud ice.
- MODIS CDNC for cloud droplet number. This affects radiation (Twomey effect), convection scheme, and warm-rain autoconversion.

Spatial coverage of NOAA-20 and EarthCARE

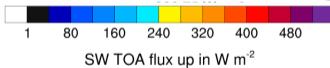
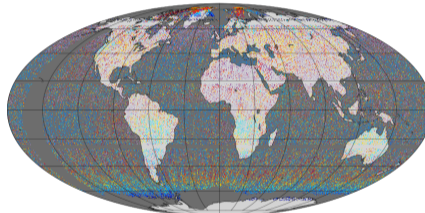
NOAA-20/CERES

SWU_T, avg = 222.92 W m⁻²



EarthCARE/BBR (all data)

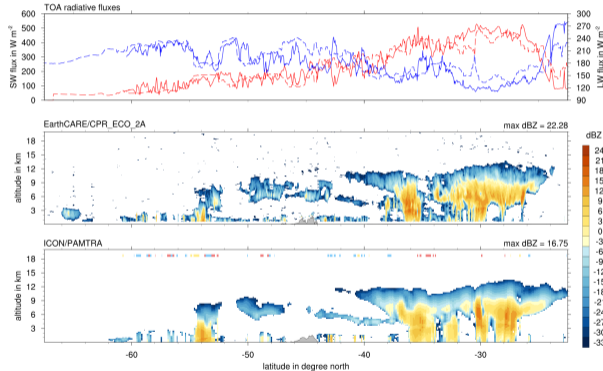
EarthCARE, avg = 227.94 W m⁻²



- Single CERES instrument gives full global coverage in a month.
- Sampling differs significantly between CERES and EarthCARE.

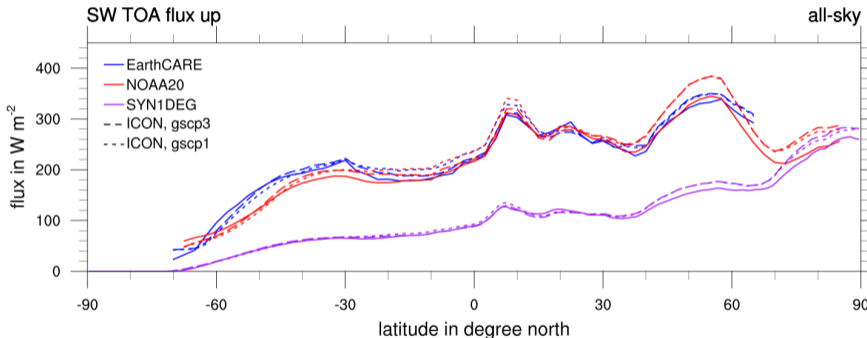
Example of EarthCARE frame and ICON forecast

2025/07/02, 00 UTC, 02:09 - 02:20 h of icon012_R3B7_gscp3
latitude: -67.5 to -22.5 N, longitude: 156.7 to 174.0 E, 6210F



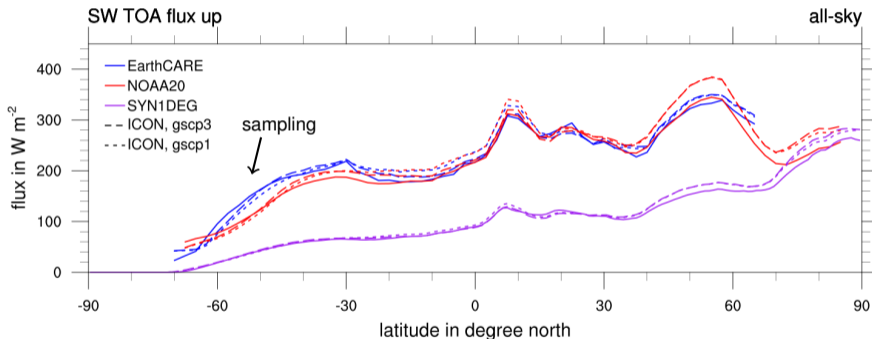
→ The island in the South Island of New Zealand.

Zonal averaged TOA radiative fluxes



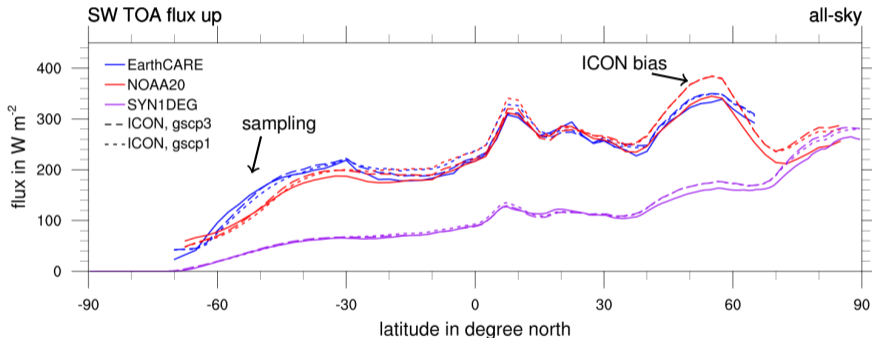
- Reasonably good agreement of ICON with corresponding observations.
- ICON can identify differences between EarthCARE and CERES that are due to sampling.

Zonal averaged TOA radiative fluxes



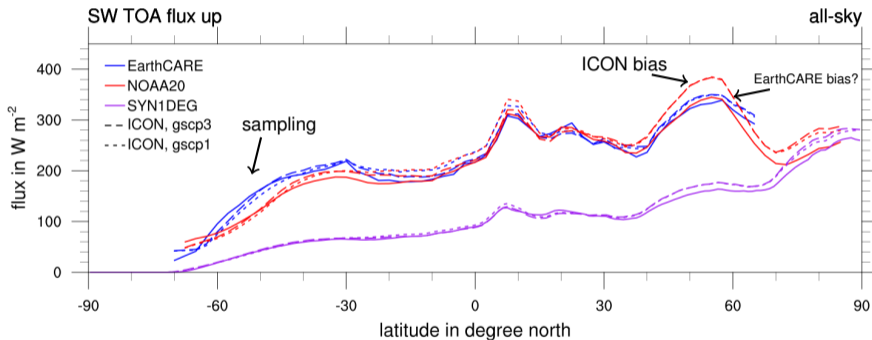
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Zonal averaged TOA radiative fluxes



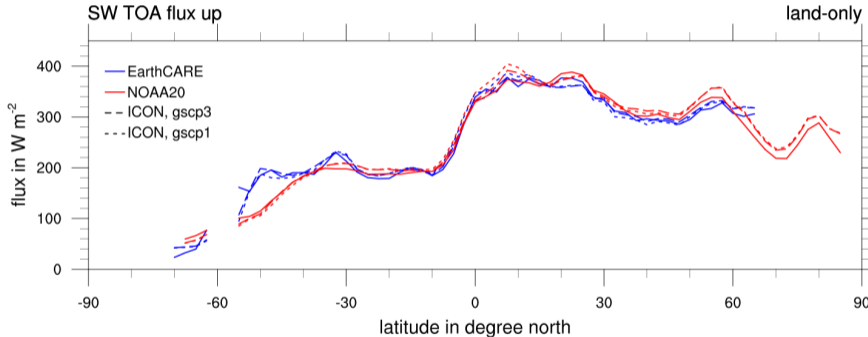
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Zonal averaged TOA radiative fluxes



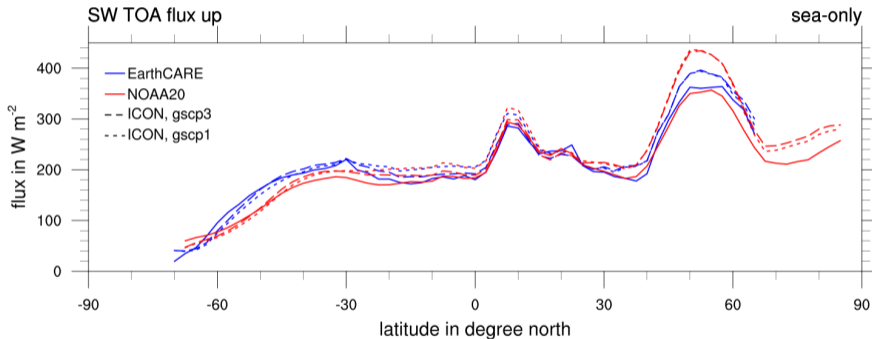
- Reasonably good agreement of ICON with corresponding observations.
- ICON can identify differences between EarthCARE and CERES that are due to sampling.

Zonal averaged TOA radiative fluxes



- ICON is even better over land.
- Pretty good match of ICON with CERES and EarthCARE.

Zonal averaged TOA radiative fluxes



- ICON still underestimates stratocumulus in subtropics, e.g., at 20 N.
- Clouds at 50 N are too bright in ICON compared to CERES, less so for EarthCARE.

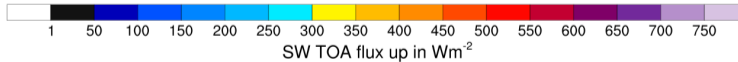
Example of CERES observations and ICON forecast

20250703, 00 UTC + 24.67 h, overpass time: 20250704, 0:30 - 0:49 UTC

CERES, avg = 292.1 Wm^{-2} , max = 831.0 Wm^{-2}



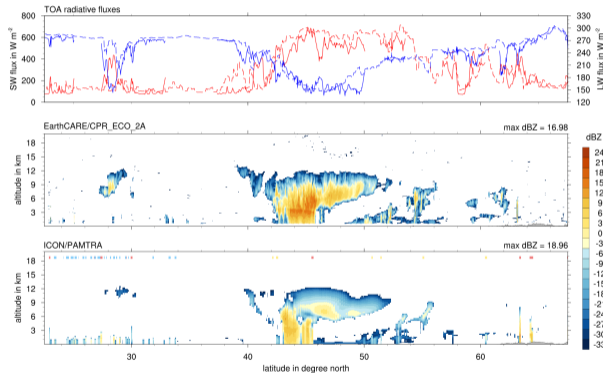
icon012_R3B7_gscp3, avg = 344.8 Wm^{-2} , max = 851.7 Wm^{-2}



→ Pacific ocean, ICON much too bright in shortwave TOA compared to CERES

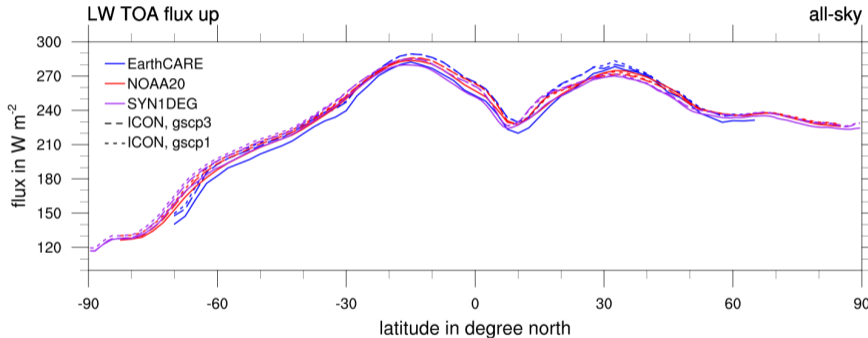
Example of EarthCARE frame and ICON forecast

2025/07/04, 00 UTC, 01:34 - 01:46 h of icon012_R3B7_gscp3
 latitude: 22.5 to 67.5 N, longitude: -174.5 to -157.3 E, 6241D



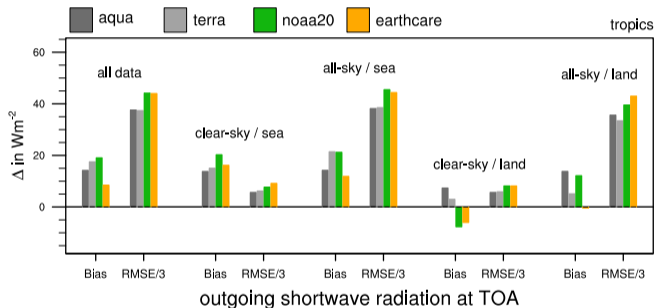
→ Pacific ocean between 40 N and 50 N, ICON slightly too bright compared to EarthCARE

Zonal averaged TOA radiative fluxes



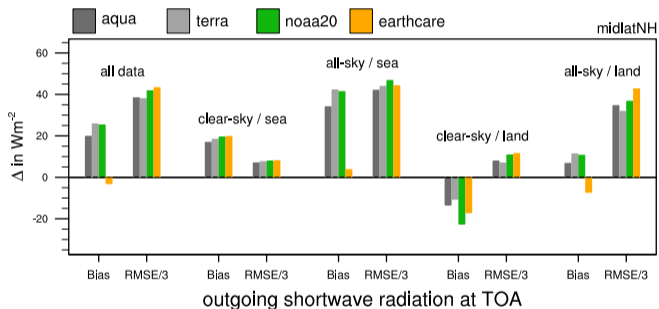
- EarthCARE seems to be low biased compared to CERES SSF.
- ICON is high biased compared to CERES SSF and EarthCARE.

Shortwave TOA in tropics using various satellites



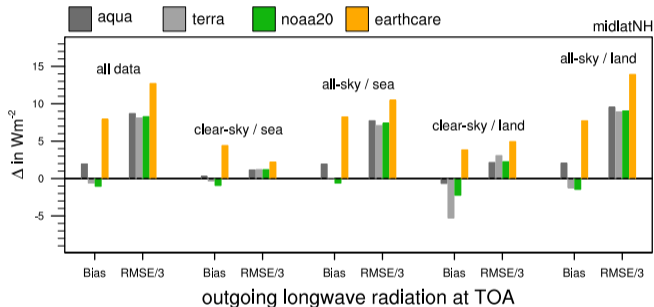
- General good agreement between CERES and EarthCARE in tropics.
- ICON has a large clear-sky shortwave bias. Aerosol issue?

Shortwave TOA for northern mid-latitudes using various satellites



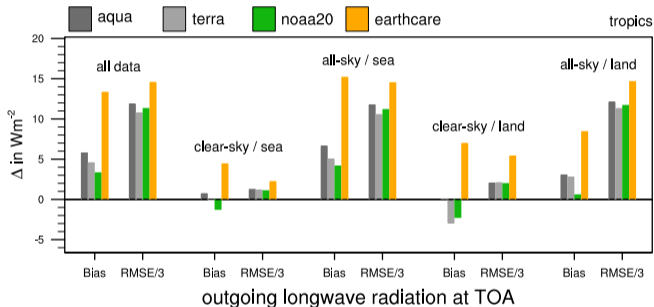
- CERES and EarthCARE seem inconsistent over mid-latitude ocean better over land.
- ICON has a large clear-sky shortwave bias. Aerosol issue?

Longwave in mid-latitude using various satellites



- The positive bias of ICON is larger for EarthCARE than for CERES.
- Hence, EarthCARE is low biased compared to CERES.

Longwave in tropics using various satellites



- The positive bias of ICON is larger for EarthCARE than for CERES.
- Hence, EarthCARE is low biased compared to CERES.

Conclusions on radiative fluxes

- Generally good agreement between ICON, EarthCARE, and CERES, especially for shortwave TOA over land.
- Over the ocean, especially clouds in the northern Pacific ocean seem brighter for EarthCARE than CERES but not as bright as ICON.
- EarthCARE thermal flux seems low biased compared to CERES for most areas.

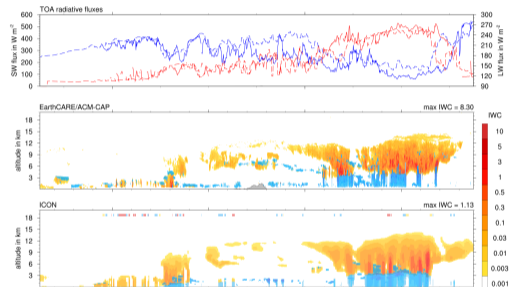
EarthCARE ACM-CAP synergistic retrievals

ACM-CAP combines ATLID, CPR, and MSI and estimates

- ice water content (IWC)
- liquid water content (IWC)
- ice and liquid effective radius

BBR radiative fluxes are not an input to ACM-CAP. But the ACM-CAP products should be consistent with BBR fluxes (radiative closure).

2025/07/01, 00 UTC, 26:09 - 26:20 h of icon073_R3B7_gscp3
latitude: -67.5 to -22.5 N, longitude: 156.7 to 174.0 E, 6210F



The little island in the center of the frame is the South Island of New Zealand.

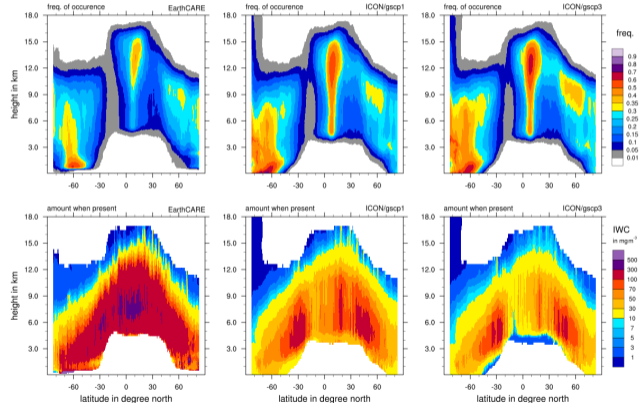
Reference: Mason, S. L., Hogan, R. J., Bozzo, A., and Ponder, N. L.: A unified synergistic retrieval of clouds, aerosols, and precipitation from EarthCARE: the ACM-CAP product, *Atmos. Meas. Tech.*, 16, 2023

Zonal cloud statistics for July/Aug 2025: ice water content

Decompose zonal mean in frequency of occurrence and amount when present.

- Cloud threshold of 1 mg/m^3 IWC
- Hence, this includes thin cirrus.
- Too high freq. in tropics.
- IWC is underestimated by ICON compared to ACM-CAP.
- Complicated due to contribution from snow and deep convection.

EarthCARE/ACMCAP vs ICON for globe

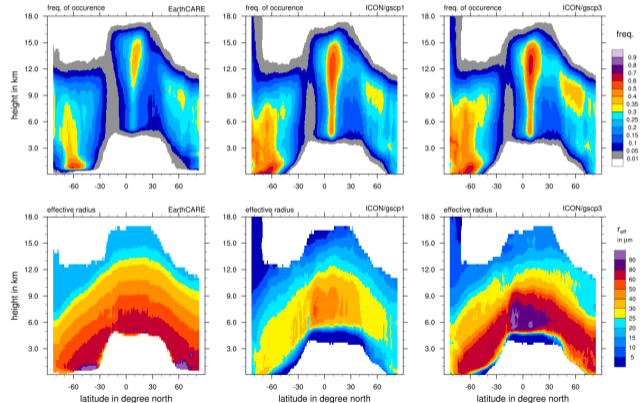


Zonal cloud statistics for July/Aug 2025: ice effective radius

Effective radius from ACM-CAP:

EarthCARE/ACM-CAP vs ICON for globe

- Operational ICON okay at cloud top, but underestimates below.
- Effective radius of two-moment ice too low at top, too high below.
- Maybe effective radius has to compensate all other biases?
- Or the other parameterizations compensate for choice of effective radius?



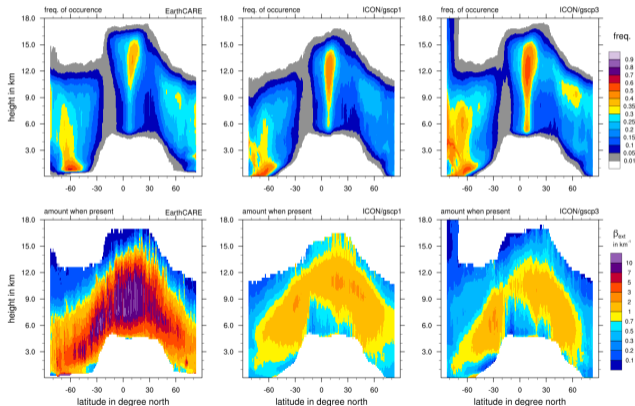
Zonal cloud statistics for July/Aug 2025: extinction coefficient

Extinction coefficient:

$$\beta_{ext} = \frac{3}{2\rho_i} \frac{IWC}{r_e}$$

→ ICON underestimates extinction by ice clouds.

EarthCARE/ACMCAP vs ICON for globe



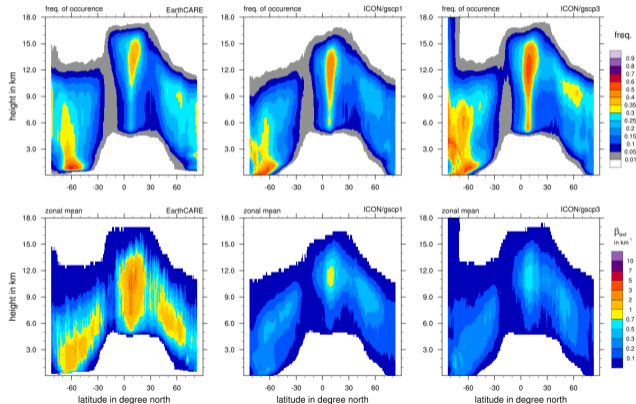
Zonal cloud statistics for July/Aug 2025: extinction coefficient

Extinction coefficient:

$$\beta_{ext} = \frac{3}{2\rho_i} \frac{IWC}{r_e} \quad (1)$$

- ICON underestimates extinction ... also for zonal mean!
- How can ICON have good TOA radiative fluxes?

EarthCARE/ACMCAP vs ICON for globe

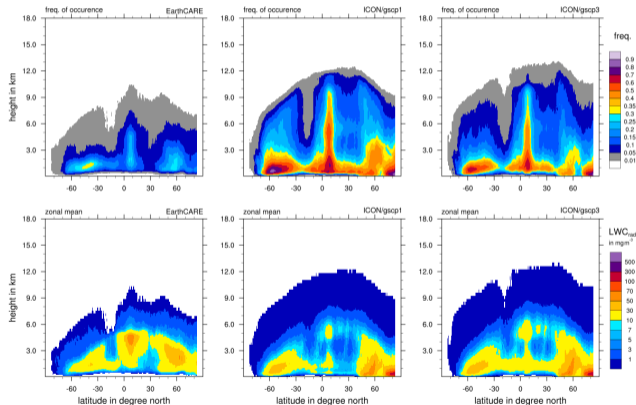


Zonal cloud statistics for July/Aug 2025: liquid water content

Liquid and mixed-phase clouds:

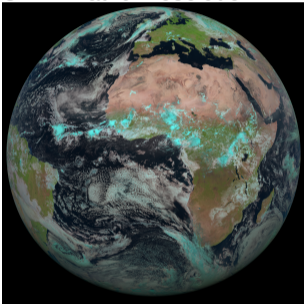
- ICON overestimates the occurrence of liquid water
- Especially low clouds.
- But also mid-level mixed-phase clouds in the tropics.

EarthCARE/ACMCAp vs ICON for globe

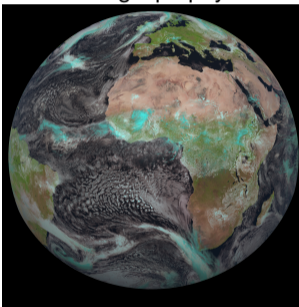


ICON vs SEVIRI using RRTOV/MFASIS: 1st July 2025

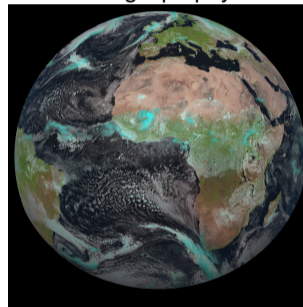
SEVIRI at full resolution



ICON with gscp1 physics



ICON with gscp3 physics



- ICON has extensive low cloud cover over oceans. This is somewhat reduced in the gscp3 physics package, but not directly related to the microphysics scheme.

Preliminary results based on EarthCARE constraints:

- TOA radiative fluxes show good agreement with observations.
- ICON with two-moment cloud ice scheme shows incremental improvements.
- ICON exhibits insufficient IWC, compensated by excessive liquid cloud cover.
- Extended Hypothesis:
 - * Deep convective heating profile is overly top-heavy.
 - * Correcting cirrus IWC triggers a positive temperature bias near tropical tropopause.
 - * Thus, high liquid cloud cover compensates for radiative balance.

EarthCARE at DWD: Summary and Conclusions

- EarthCARE provides high-resolution data for model development.
- These observations are crucial for understanding aerosol-cloud-radiation interactions.
- ICON demonstrates high fidelity in dBZ, radiative fluxes, and cloud statistics.
- Identified model biases help to provide a roadmap for future development.
- The dominant role of the deep convective scheme can hinder quantitative evaluation.
- Next Steps: Deepen analysis of cloud-radiative effects and use EarthCARE aerosol data.