Some challenges for the representation of clouds
A global model perspective

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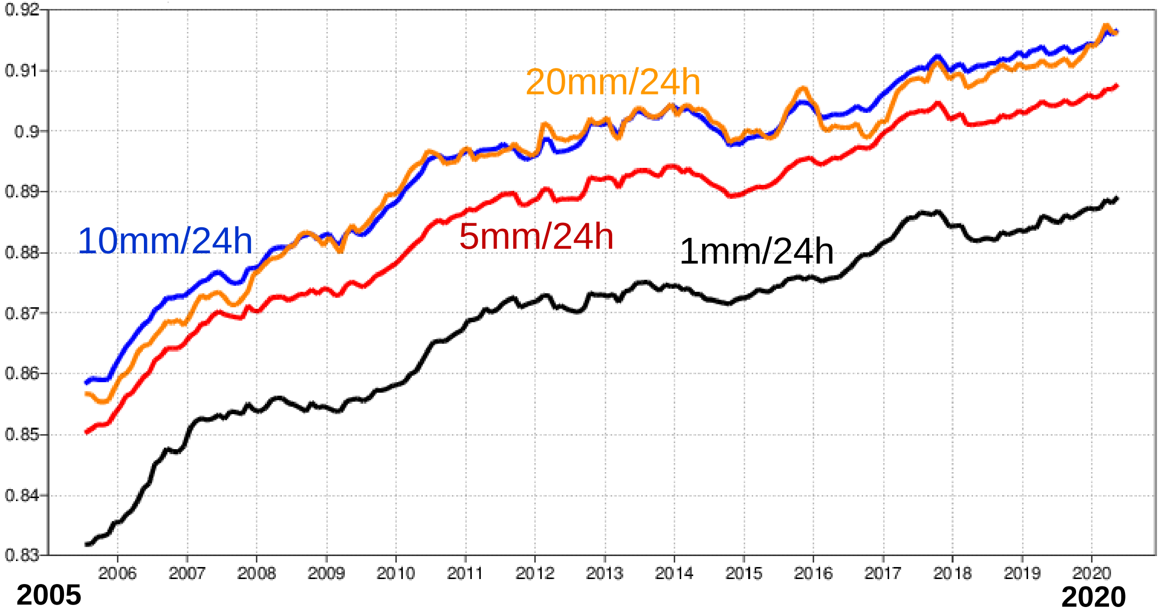
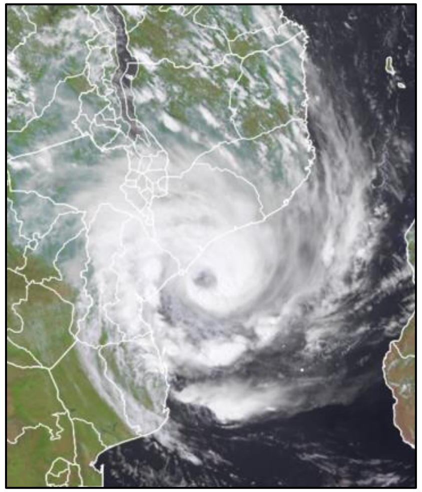
With thanks to ECMWF colleagues
particularly Philippe Lopez and Mark Fielding, Alan Geer, Simon Lang for figures

Global numerical weather prediction – impacts on lives

Increasing forecast skill over the last 15 years for precipitation from the operational ECMWF IFS global ensemble system



Timeseries of Discrimination score (ROC area) for extratropics oper IFS forecast day 5. Measures the ability of the forecast to discriminate between events and non-events for different precipitation thresholds.



(1) Global modelling extending to the 1 km grid scale

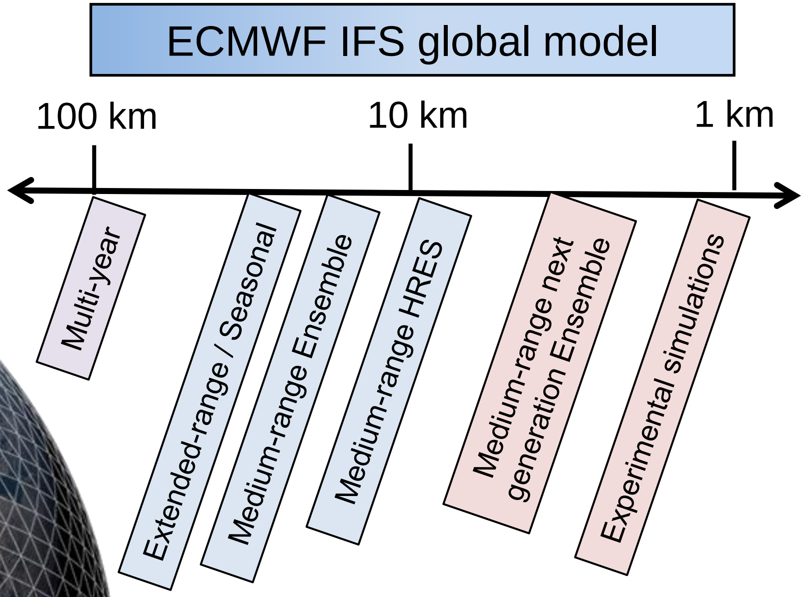
- The increasing computational power and advances in computational science are allowing higher resolution and the potential for more realistic physical parametrizations

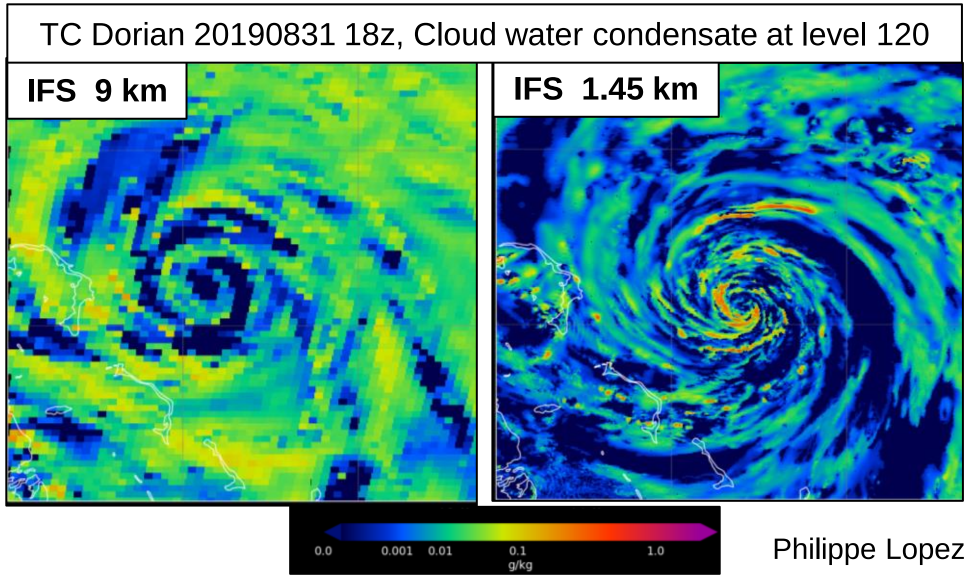
- Global models need parametrizations appropriate from O(1 km) to O(100 km)

- Opportunity to improve parametrizations across space and time scales!
  (scale-aware/independent, convergence, accuracy, numerical robustness, efficiency…)

Destination Earth (DestinE)
Digital Twins, Data lakes, AI/ML, GPUs, EuroHPC
https://digital-strategy.ec.europa.eu/en/library/destination-earth

INCITE 4-month 1.45 km IFS simulation on Summit (Dueben et al. 2020 JMSJ; Wedi et al. 2020 JAMES)



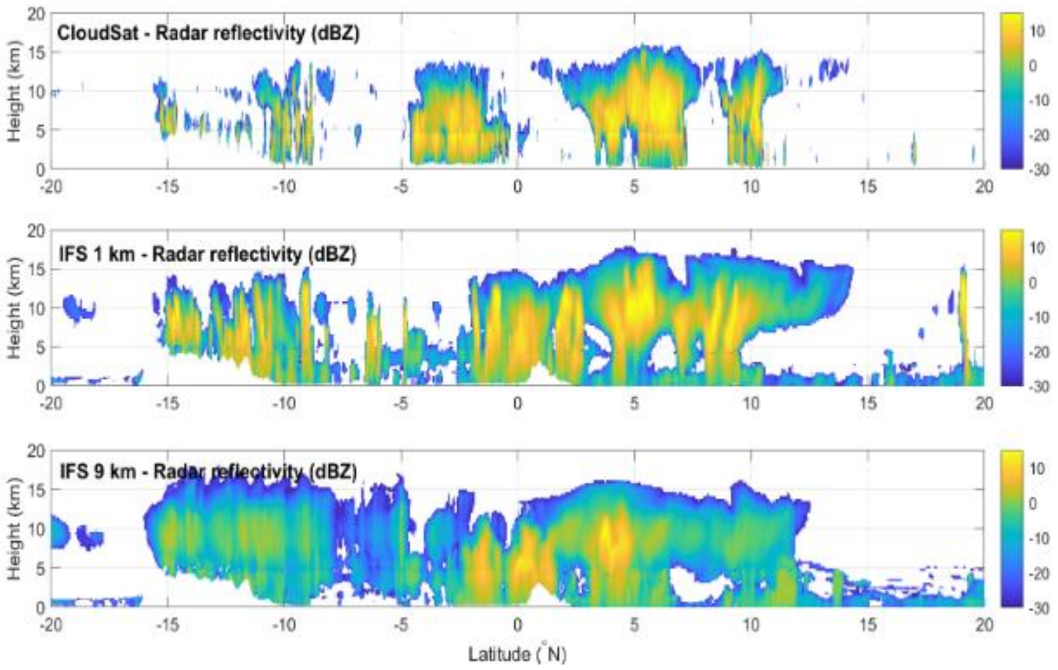


Philippe Lopez

(2) Increased focus on microphysics fidelity/realism

- More resolved dynamics, less subgrid assumptions
- The details of the microphysics are increasingly important for accurate cloud/precipitation and impacts
  (rather than dominated by the uncertainty of the subgrid – cloud fraction, parametrized convection…)
- Forward modelling/observation operator increasingly important for data assimilation and model evaluation
- Towards increased consistency of microphysical assumptions across the model
- ECMWF global IFS moving towards a flexible framework for multi-moment microphysics

Comparison of a cross-section (20°S to 20°N) of radar reflectivity from (a) CloudSat, (b) IFS 1.4km simulation, (c) IFS 9 km simulation



Mark Fielding, Marta Janiskova

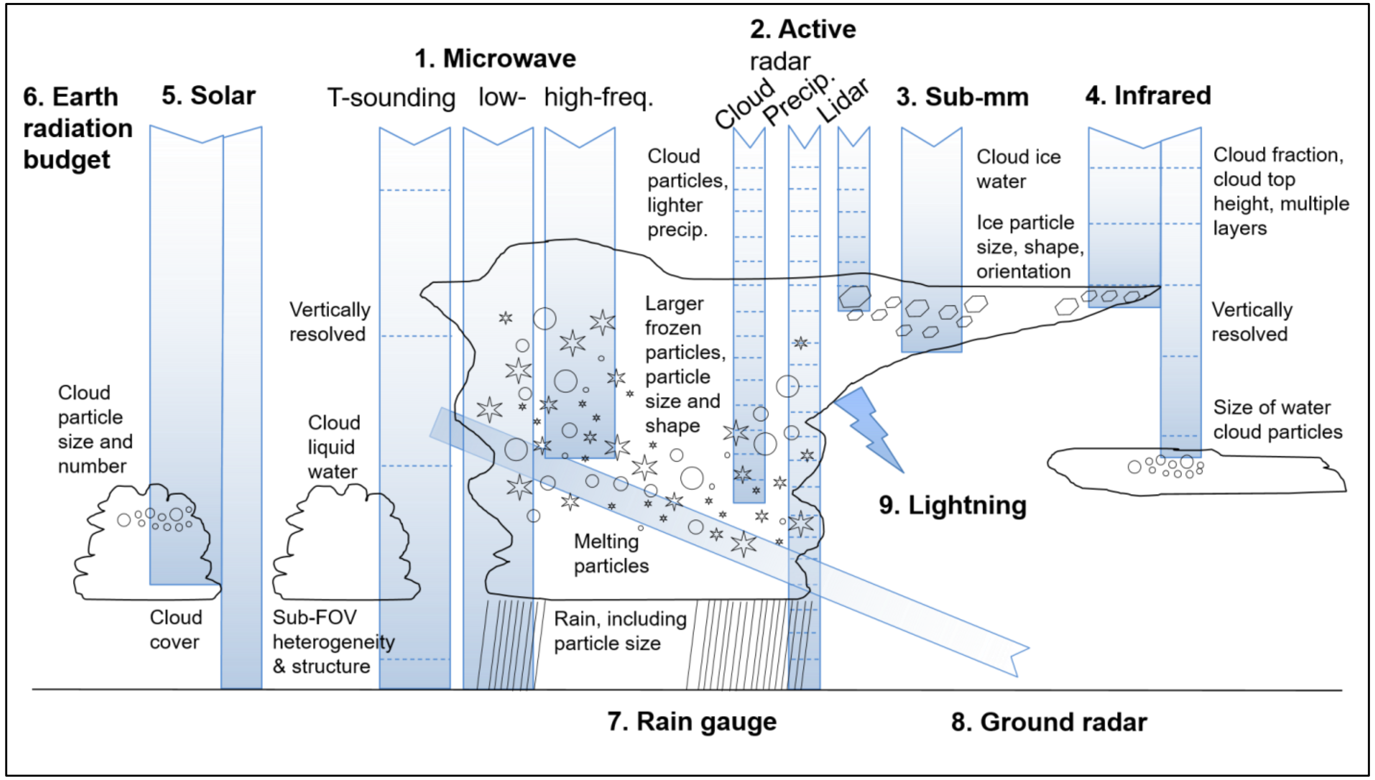
(3) Constraining microphysical parametrization globally

- Increasing amounts of data from passive and active satellite instruments can help to constrain properties of modelled cloud and precipitation globally, combined with ground-based observations

- One example at ECMWF - data assimilation background observation departures to constrain bulk quantities such as total column cloud water

- But there is much more information to extract on cloud/precip particles in the existing multi-frequency data, and from future missions (e.g. EarthCARE, ICI)

- Possible to globally constrain particle mass, phase, density, size, shape in multi-moment microphysics parametrization?



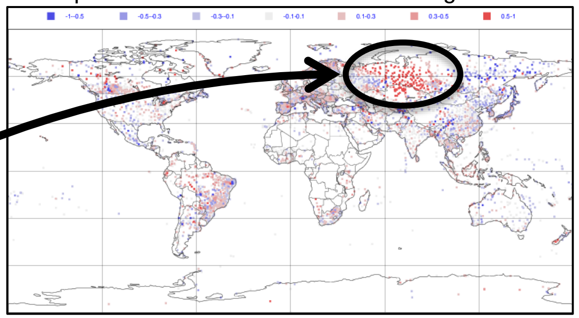
(3) Constraining microphysical parametrization globally

Example: various observations constraining latest IFS physics changes

1. Change to total column cloud liquid water (TCLW) due to pre-47r3 physics package. Decrease is beneficial. Increase over Russia and SH storm track?

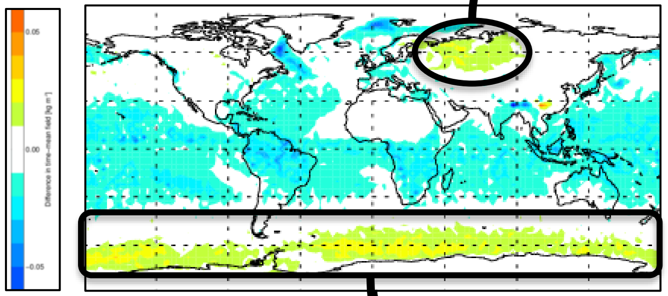
Degradation of 2m temperature

2m temperature mean absolute error change vs SYNOP

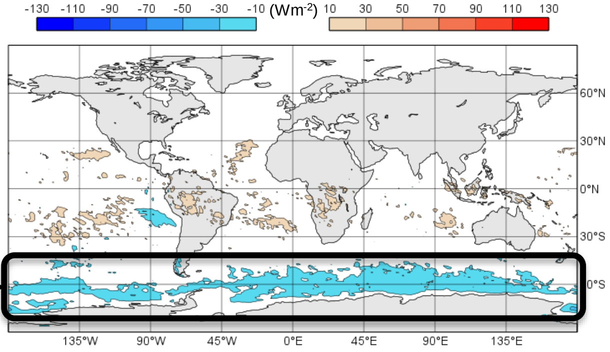


2. Increased ice deposition rate brings supercooled TCLW back to original removing degradations but leaving beneficial reduction over lower latitudes

Total column liquid water mean change (~0.01 kgm^{-2})



Top-of-atmosphere net SW radiation mean change



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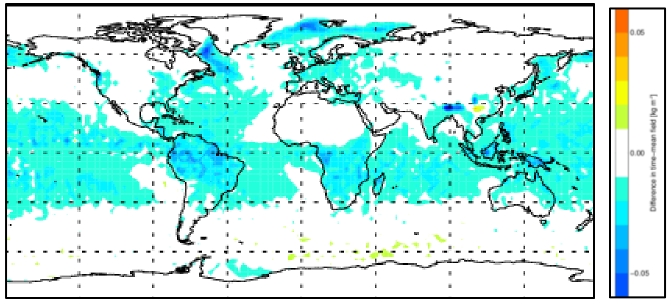
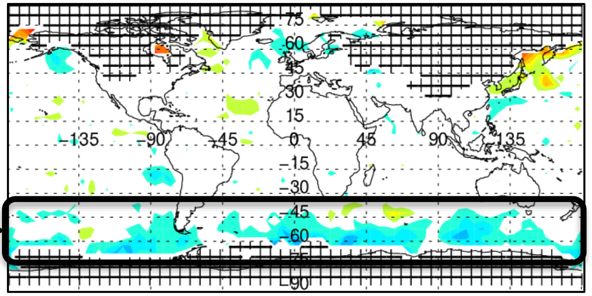


Degradation of TOA shortwave radiation

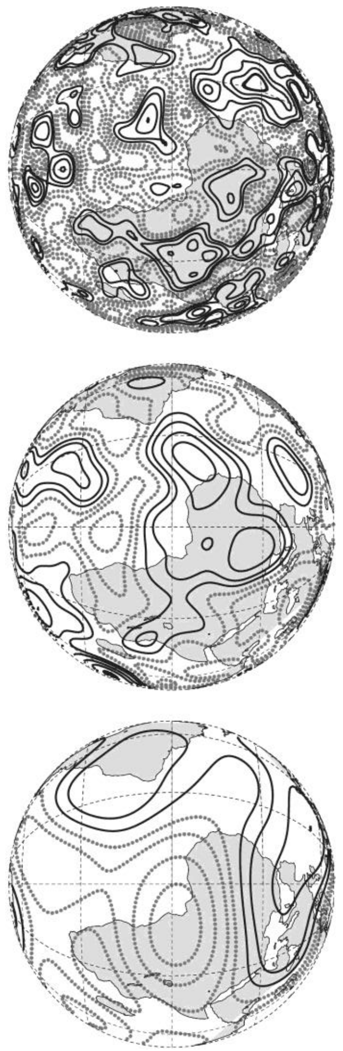
All-sky 92GHz SSMIS bg departures mean change



Degradation of all-sky cloud liquid sensitive microwave background departures

(4) Quantifying uncertainty at the process level

- The atmosphere is chaotic – ensembles are needed, representing uncertainty is vital
- How to best represent the uncertainty in cloud/precipitation processes?
- Current operational scheme at ECMWF: **SPPT** – stochastically perturb total T/Q/UV tendencies from parametrizations (including cloud) at various space and time scales (grid-scale perturbations have little impact)
- Working on next scheme: **SPP** – process level representation of model uncertainties closer to source – stochastically perturb parameters/processes. Different possibilities.


Examples of 2D random fields at different scales

Different levels to perturb **microphysics** as one part of a stochastic uncertainty scheme

SPPT	Current SPP (mphys)	SPP ? (mphys)
Microphysics as part of total parametrization tendency (T,Q)	Rain evaporation rate Snow sublimation rate Ice aggregation rate	Particle size distributions Ice particle habit Ice particle densities Collection efficiencies

SPPT: Buizza et al. (1999), Leutbecher et al. (2017), Lock et al. (2019).
SPP: Ollinaho et al. (2017, QJRMS), Lang et al. (2021, QJRMS)

Some challenges for the representation of clouds in global models

Observational campaigns (e.g. EURECA)

LES/SCM and process modelling

Research scientists

1. Global modelling **extending** to the 1 km grid scale
2. Increased focus on microphysics fidelity/realism
3. Constraining **microphysics** parametrization globally
4. Quantifying uncertainty at the process level

Global observations Existing and new

New computational resources e.g. HPC, GPUs, big data, DestinE initiative

Machine Learning