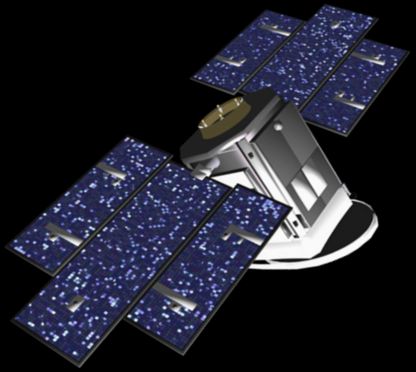
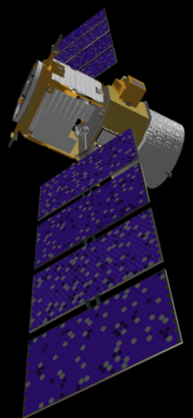
An Unprecedented Confrontation Global NWP vs CALIPSO-CloudSat

10 Years of CALIIPSO-CloudSat
Paris, 8-10 June 2016

Richard Forbes
European Centre for Medium-Range Weather Forecasts (ECMWF)





With thanks to Maike Ahlgrimm, Alan Geer, Marta Janisková, Frank Li, Katrin Lonitz

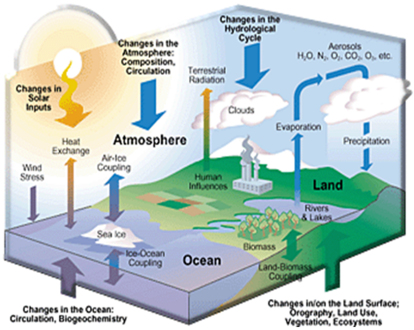
Global Numerical Weather Prediction
➔ High resolution Earth System Modelling

Analysis and forecast system at ECMWF

- Global high resolution analysis and forecasts (dx=9 km) to 10 days
- 51 member ocn/atm coupled ensemble to 15 days (dx=18 km)
- Ensemble of monthly and seasonal forecasts at lower resolution
- COPERNICUS atmospheric composition analysis
- Reanalyses ERA-I➔ERA5 (1979-) & ERA-20C (20th Century)

Components

- Atmosphere
- Land, hydrology
- Ocean, sea-ice
- Atmospheric composition



Global prediction

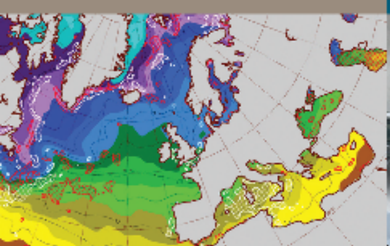
- Weather forecasts with focus on high impact weather
- Longer term trends (monthly, seasonal)
- Predicting predictability (representing uncertainty – ensembles)

Representing reality across space and time scales

- NWP is an initial value problem, but not every aspect is constrained
- The forecast quickly drifts towards its own “climate”
- Need a physical and dynamical model as close to reality as possible

An accurate representation of clouds and precipitation is vital!

GLOBAL PREDICTION



SEVERE WEATHER

ATMOSPHERIC COMPOSITION

CLIMATE MONITORING

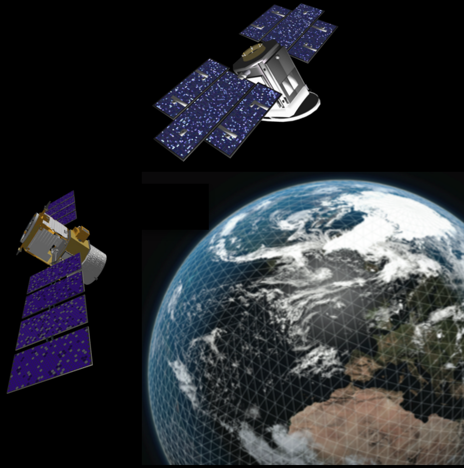
SUPERCOMPUTER CENTRE

The three relationship stages of global NWP vs. CALIPSO/CloudSat

1. Confrontation
   (Model Evaluation)

2. ?

3. ?

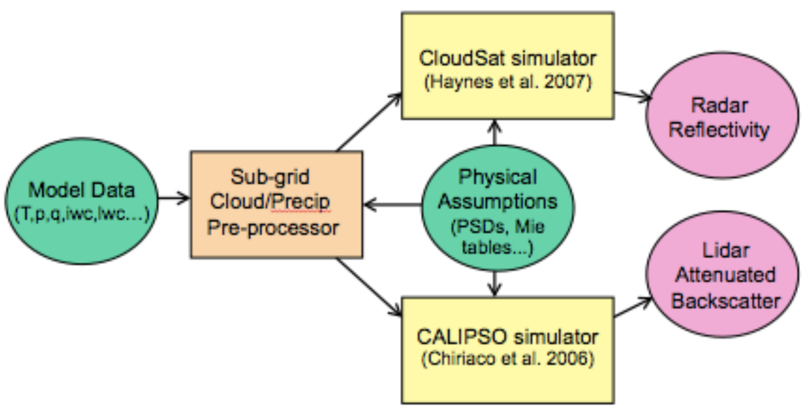


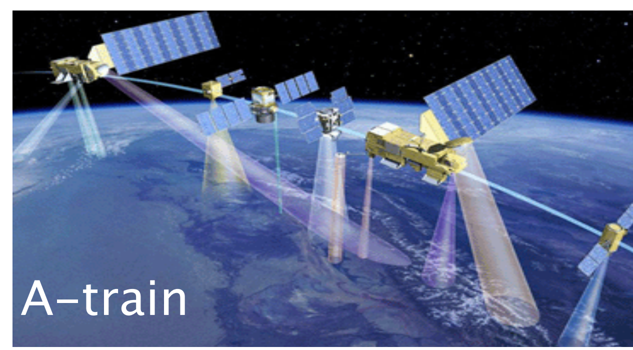
Confronting models with observations
The first step is how to do a fair comparison

- Both observational and modelling communities, we've been learning!
- Take the observations to the model (geophysical retrievals) or the model to the observations (forward modelling/ simulators)
- We need both approaches

Examples:

- CloudSat & CALIPSO level 2 and 3 products
- DARDAR (Delanoë and Hogan, JGR, 2010)
- C … bs)
- G



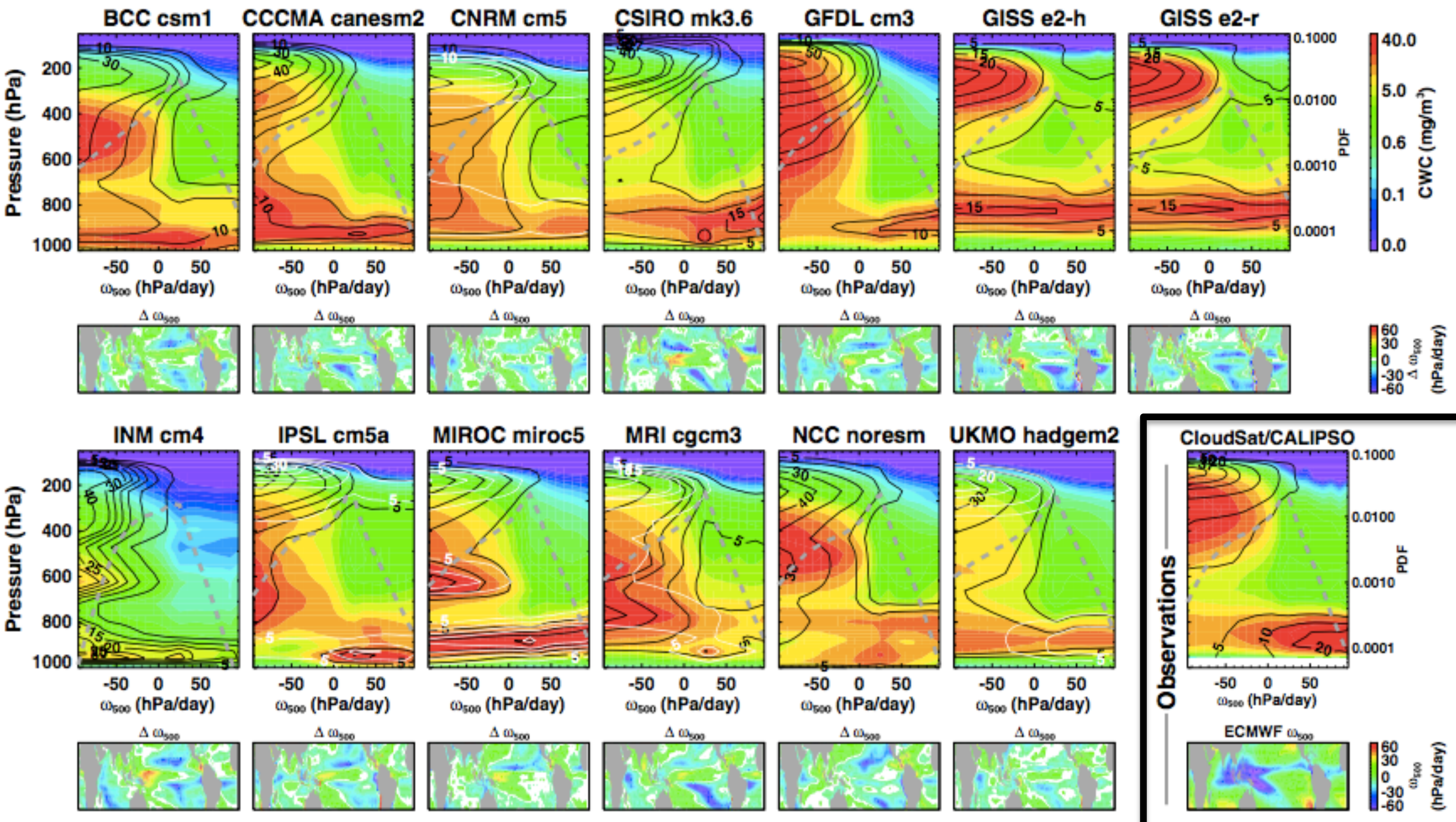


GCM clouds differ significantly from CloudSat/CALIPSO Differences are mainly due to deficiencies in model physics

Example: Vertical profile of **cloud water content**

Su et al. (2013)

Vertical profiles of cloud water content from CMIP5 models and CloudSat/CALIPSO as fn(ω_{500})

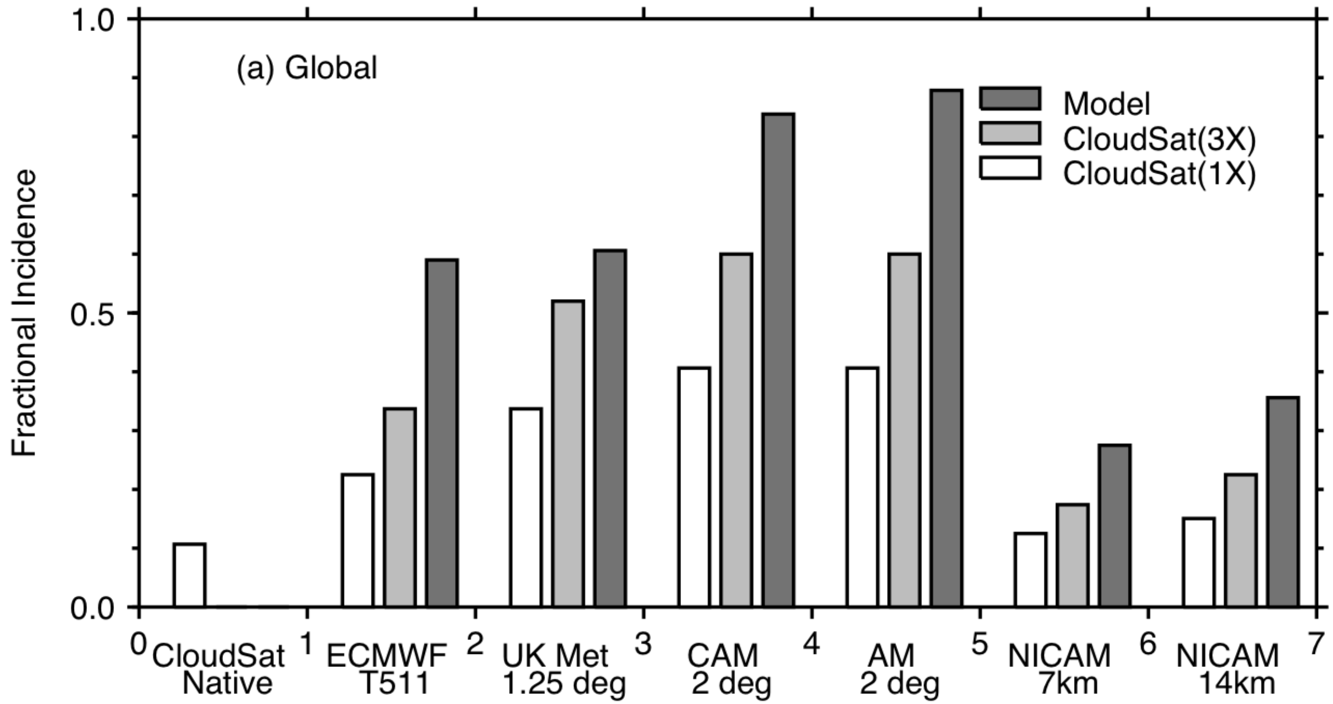


GCM clouds differ significantly from CloudSat/CALIPSO Differences are mainly due to deficiencies in model physics

Example: Too frequent **light precipitation** over ocean

Stephens et al. (2010)

Fractional incidence (or frequency of occurrence) of rainfall as a function of rainfall rate over ocean (60°S to 60°N) derived from CloudSat and various gl



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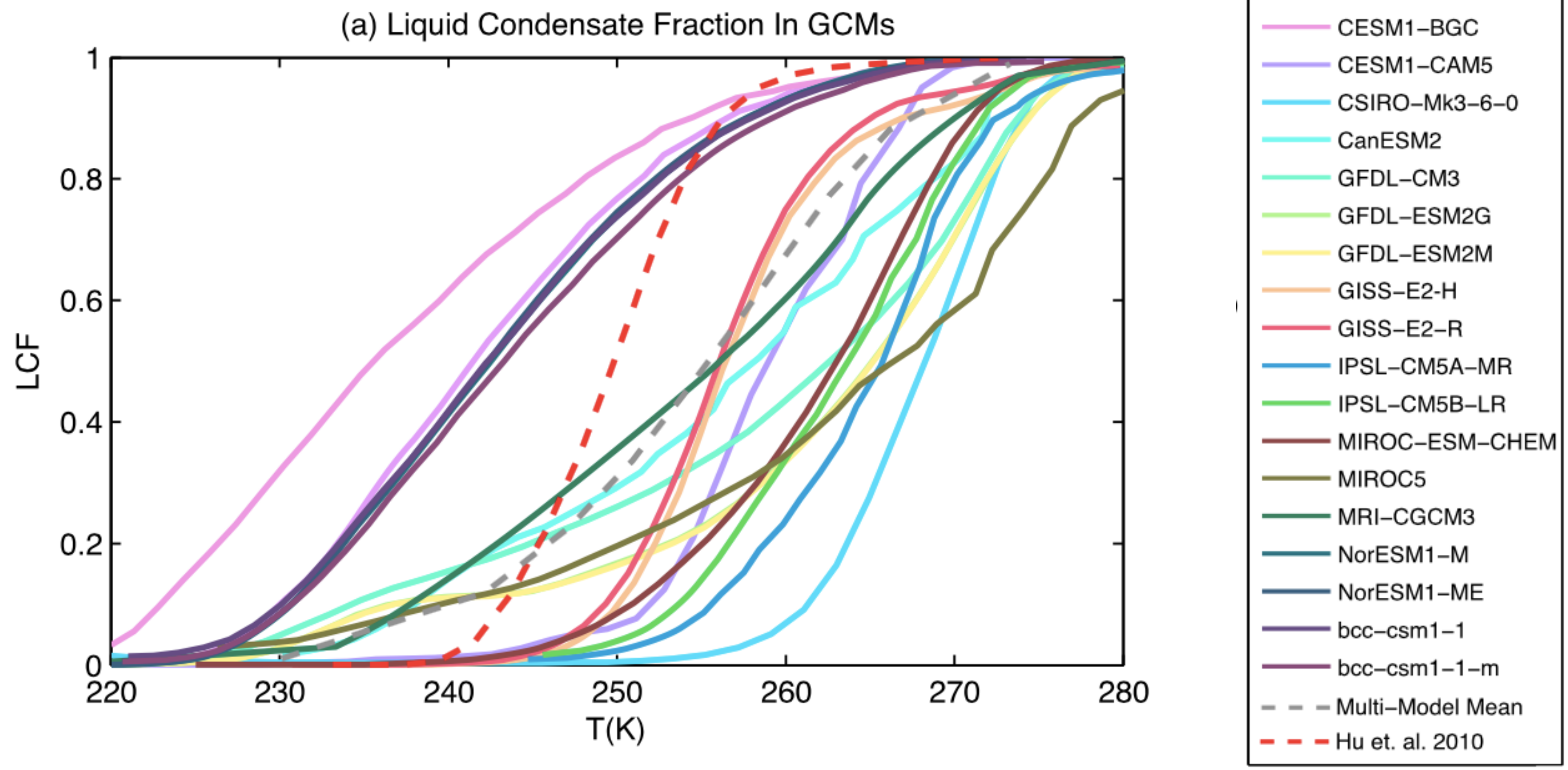
Example: Wide variation of **supercooled liquid water** fraction

McCoy et al. 2015

CMIP5 models and CALIPSO Obs



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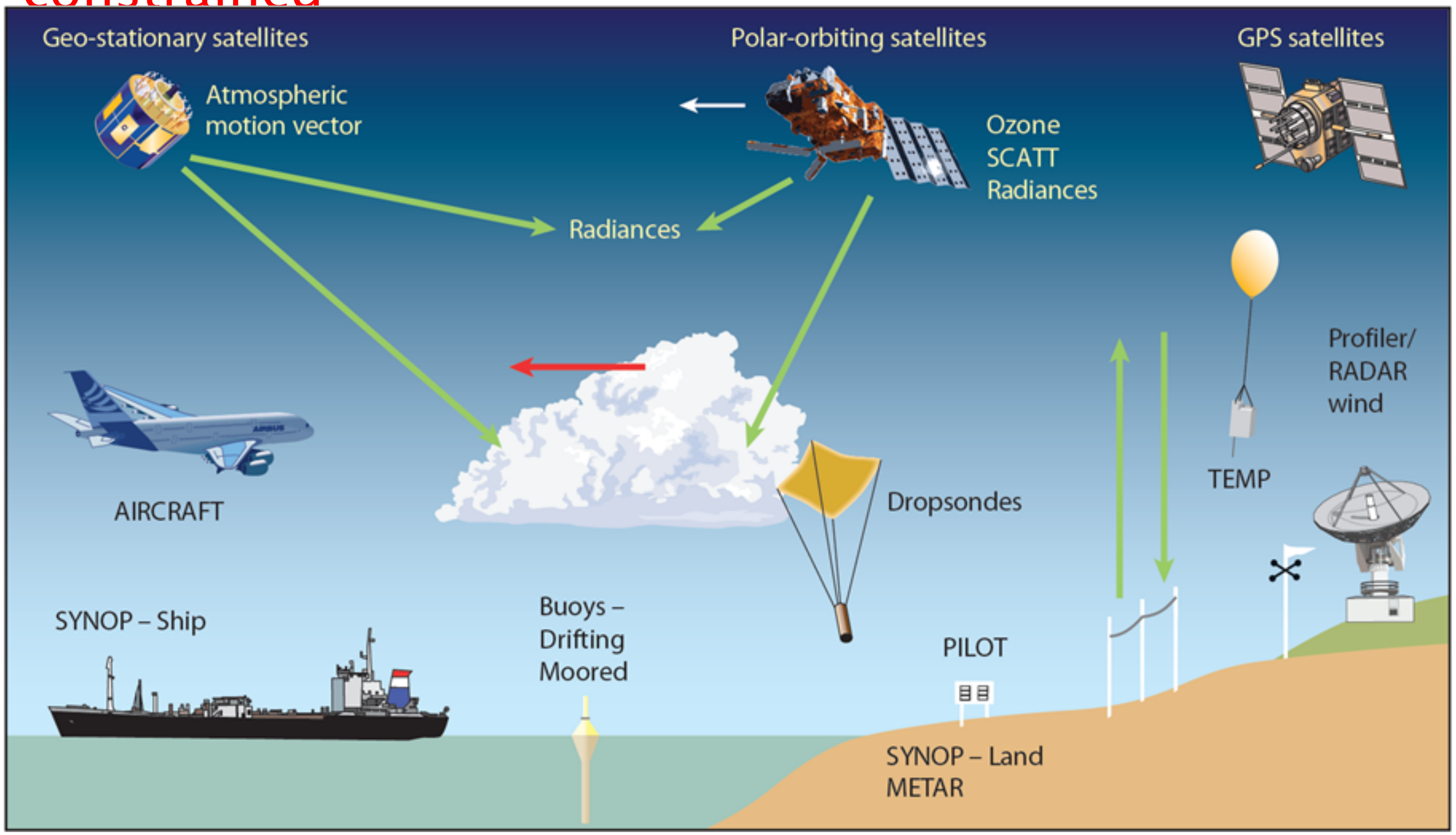
Cesana and Chepfer (2013), Cesana et al (2015), …

NWP analysis clouds differ significantly from CloudSat/ CALIPSO
Differences are mainly due to deficiencies in model physics

Millions of observations are assimilated every day at ECMWF

…yet cloud ice/water content and phase are not well-constrained



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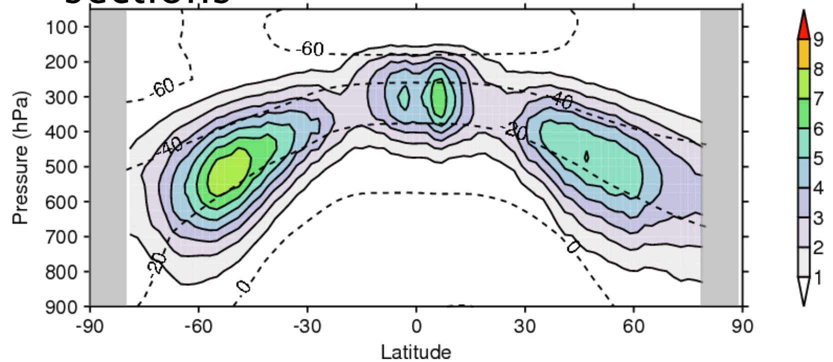
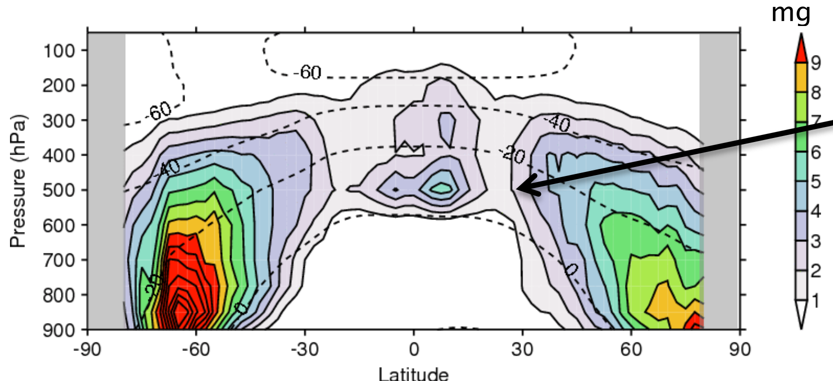
NWP analysis clouds differ significantly from CloudSat/ CALIPSO
Differences are mainly due to deficiencies in model physics

Ice water content zonal cross-sections

CloudSat
(non-convective, non-precipitating derived ice water) (courtesy Frank Li)

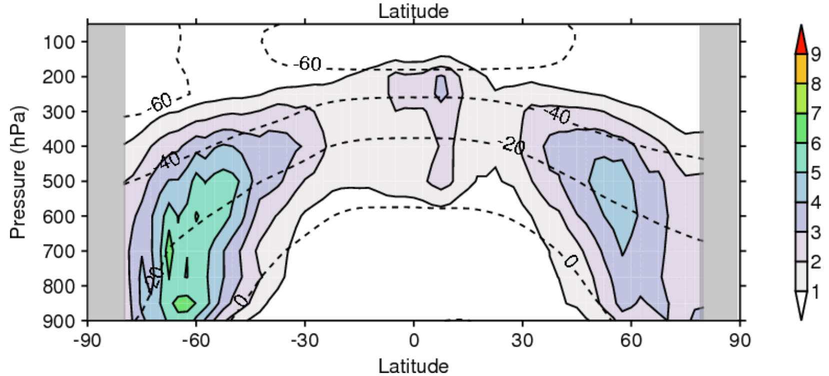


ERA-Interim



Spurious IWC max 0 to -23C due to physics assumptions

IFS with improved cloud physics operational in 2010



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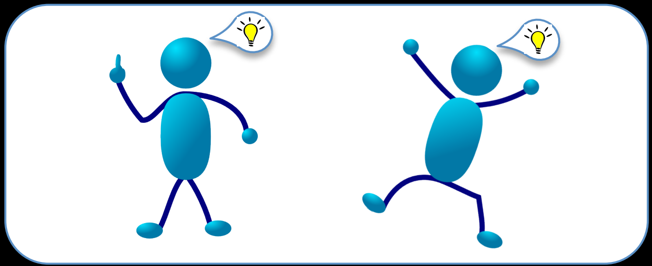
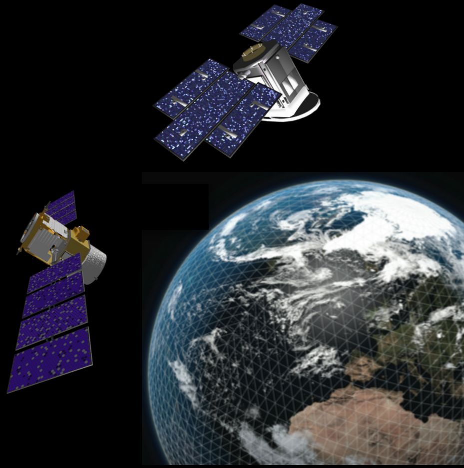
The three relationship stages of global NWP vs. CALIPSO/CloudSat

1. Confrontation
(Model Evaluation)

2. Understanding
(Improving the model)



3. ?

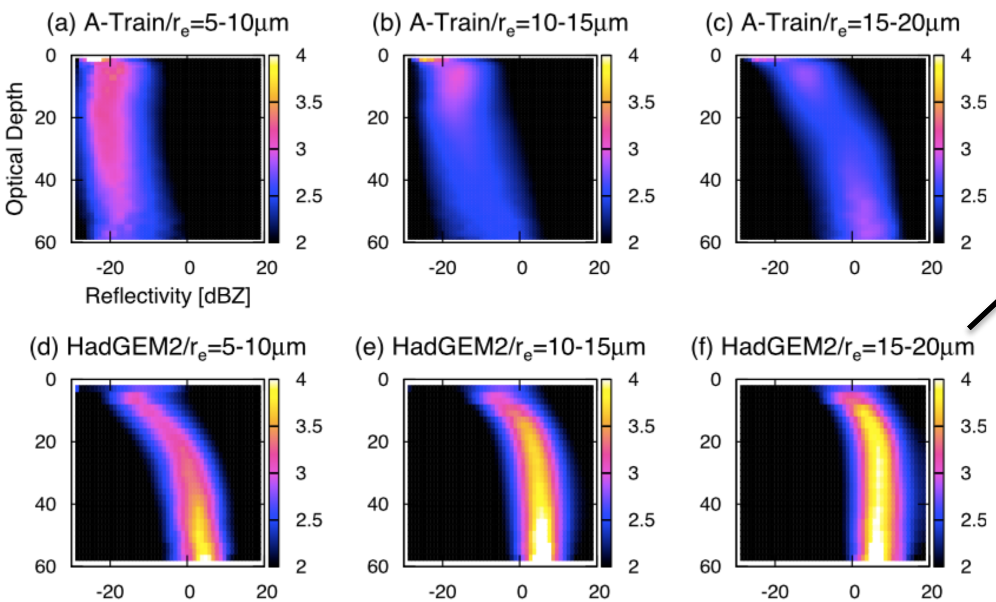


Understanding processes – improving parametrizations Using observation synergy and modelling studies

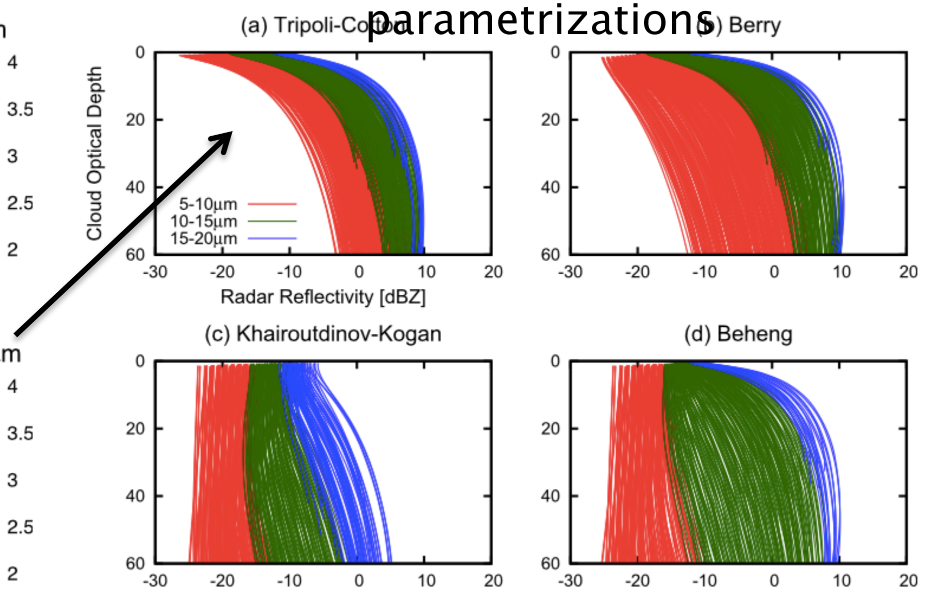
Example: Warm-rain formation process using A-Train data, GCMs and process models.

Suzuki et al. 2015

Z vs Optical Depth for different R_{eff} from CloudSat/MODIS and from the HadGEM2 model



Effect of different autoconversion parametrizations



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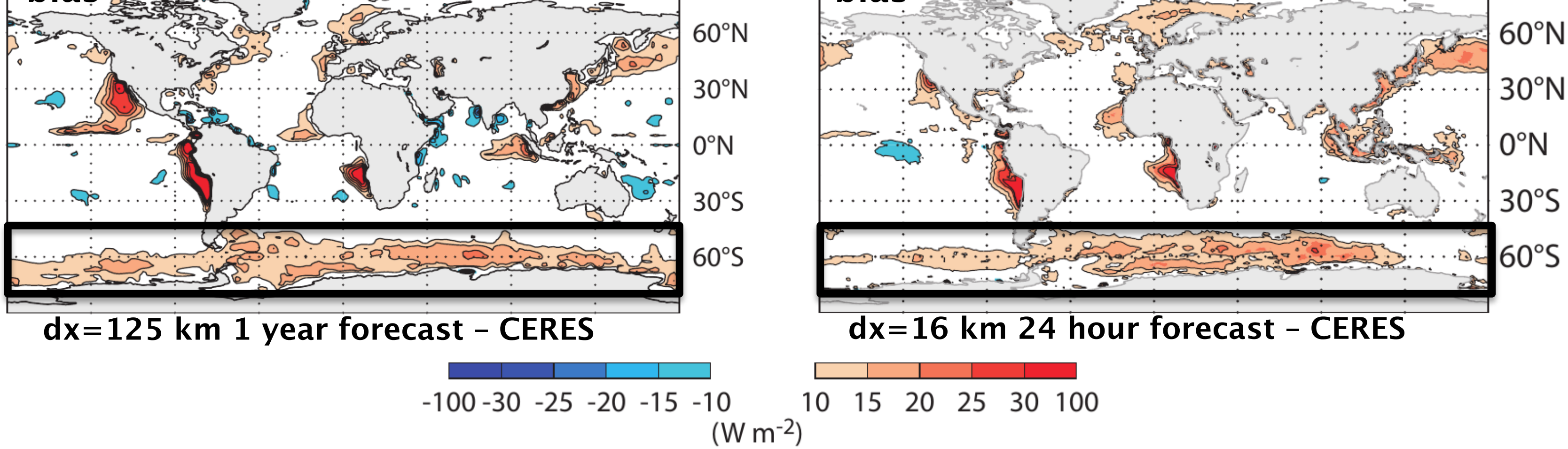
Understanding processes – improving parametrizations
Using observation synergy and modelling studies

Example: The Southern Ocean SW radiation bias

Forbes et al. 2016
(ECMWF Newsletter 146)

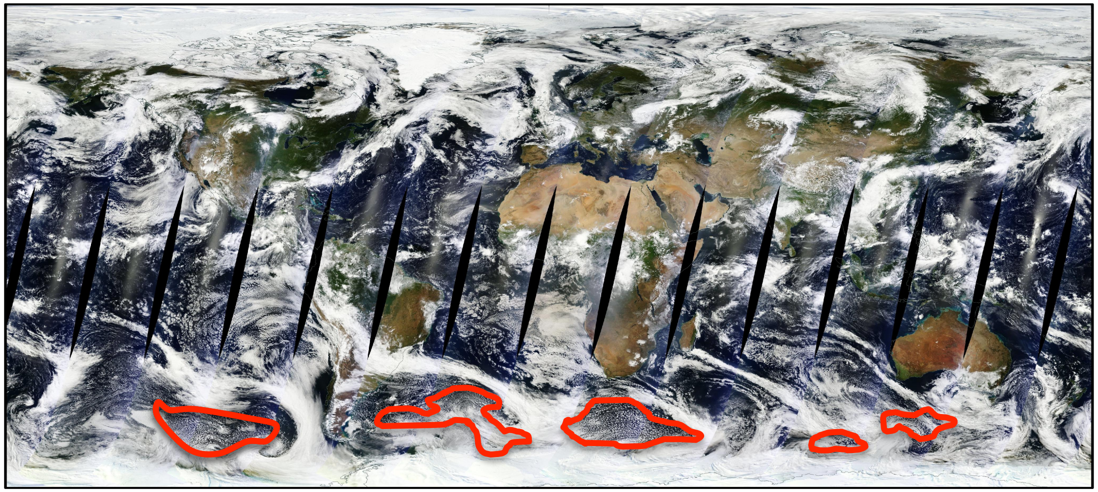
Annual mean 10–20 Wm^{-2} TOA SW bias (too little reflection) over Southern Ocean

ECMWF low resolution “climate” bias | **ECMWF high resolution “analysis” bias**

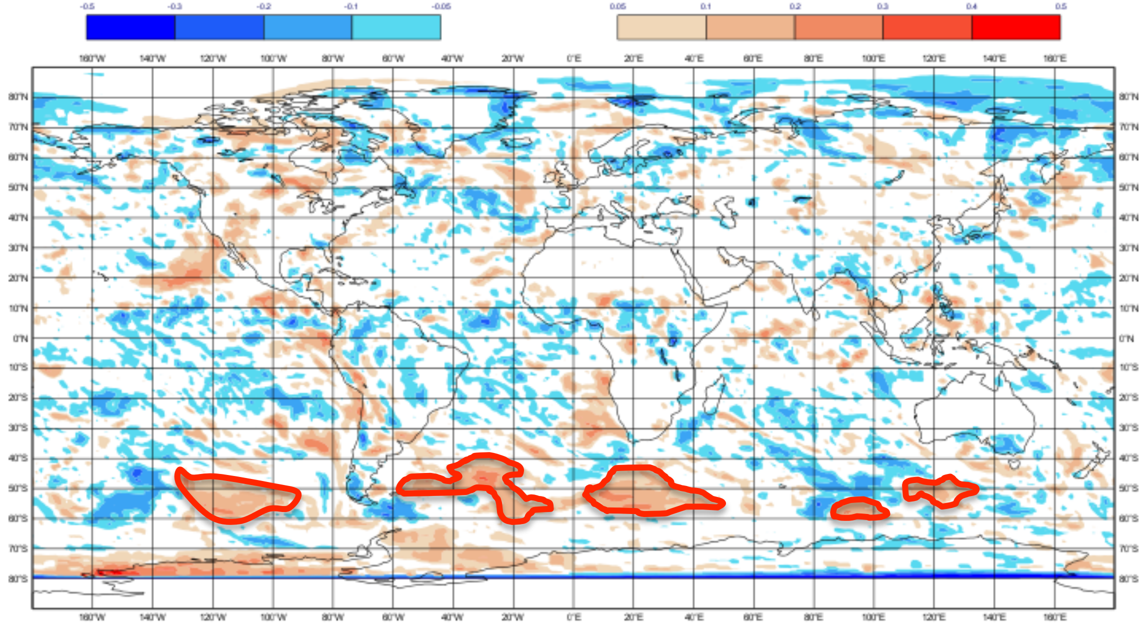


ECMWF

A snapshot of the IFS TOA SW radiation error shows the problem in the IFS



MODIS
visible
24 Aug 2013

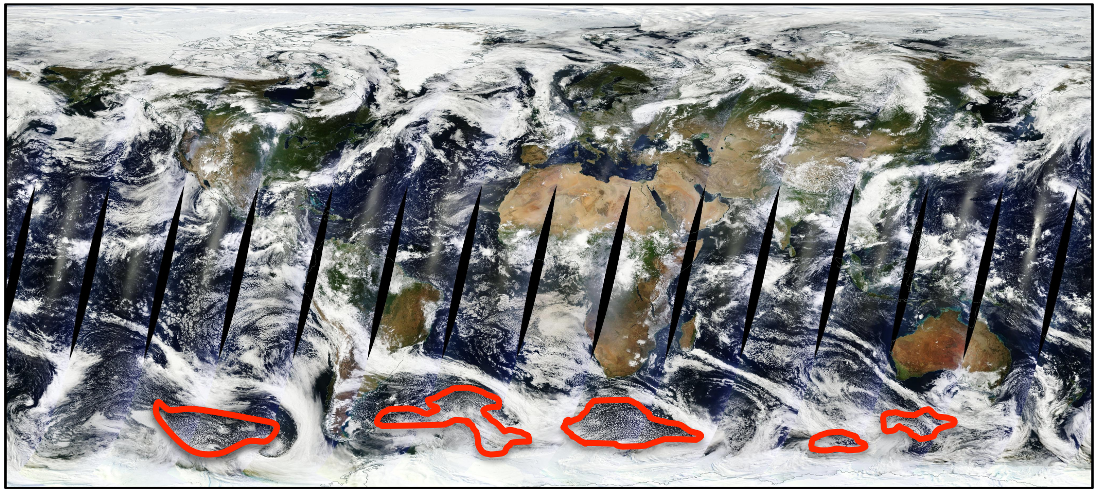


IFS 24 hour TOA net SW radiation bias vs **CERES**
24 Aug 2013

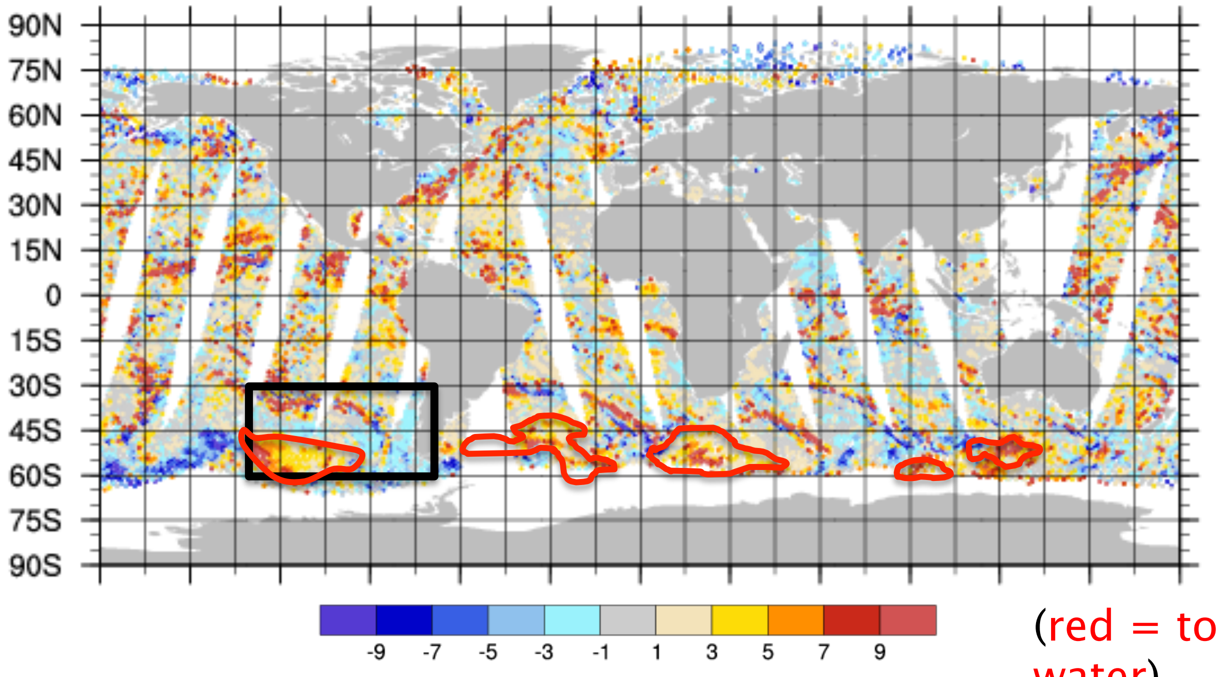
(red = not reflective enough)

ECMWF

A snapshot of the IFS data assimilation system first guess departures for SSMIS 37 GHz brightness temperatures (sensitive to LWP)



MODIS visible
24 Aug 2013



IFS **SSMI/S** 37GHz analysis first guess brightness temperature errors
24 Aug 2013

(red = too little liquid water)

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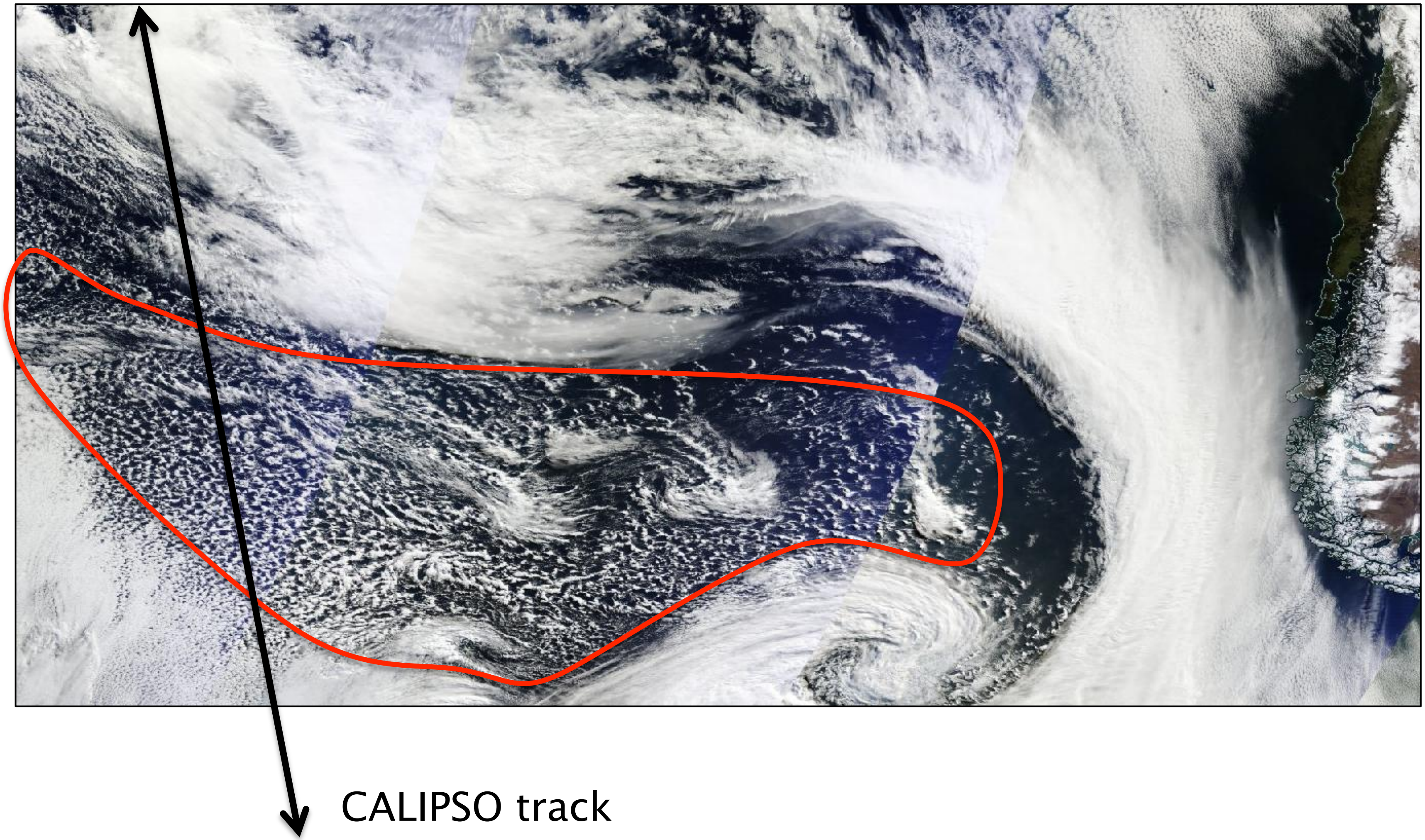
The problem is a lack of supercooled liquid water at the tops of convective clouds in cold-air outbreaks



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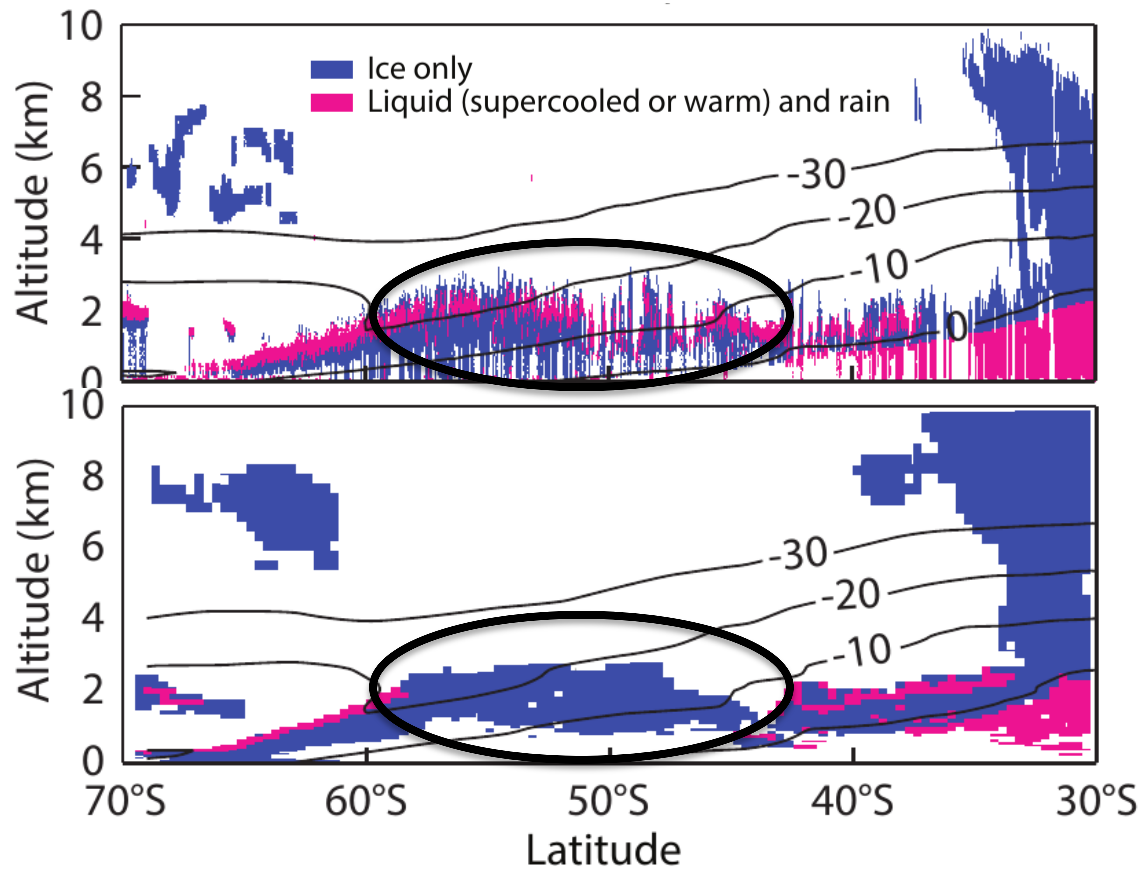

CALIPSO satellite lidar cloud phase

IFS along-track lidar forward modelled cloud phase

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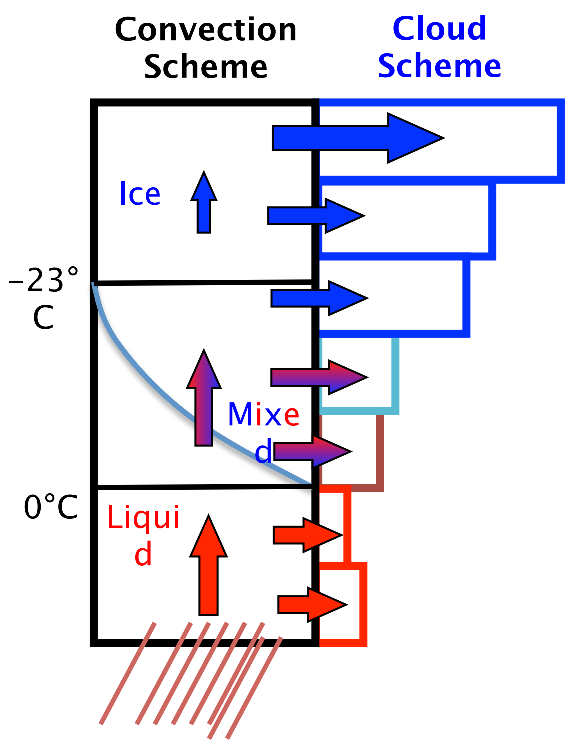
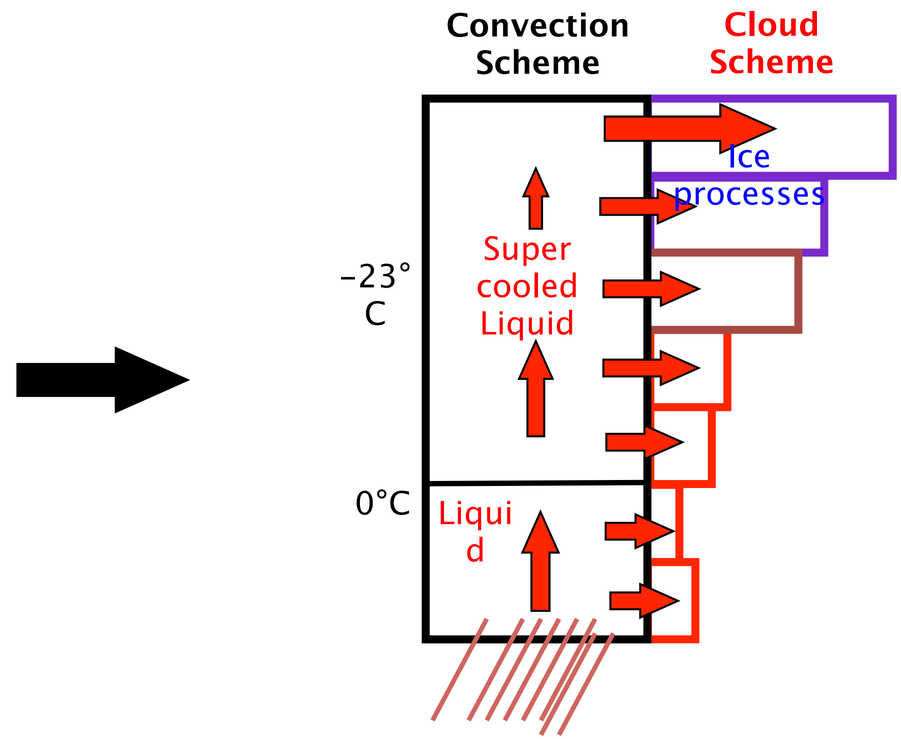
Parametrized convection and microphysics



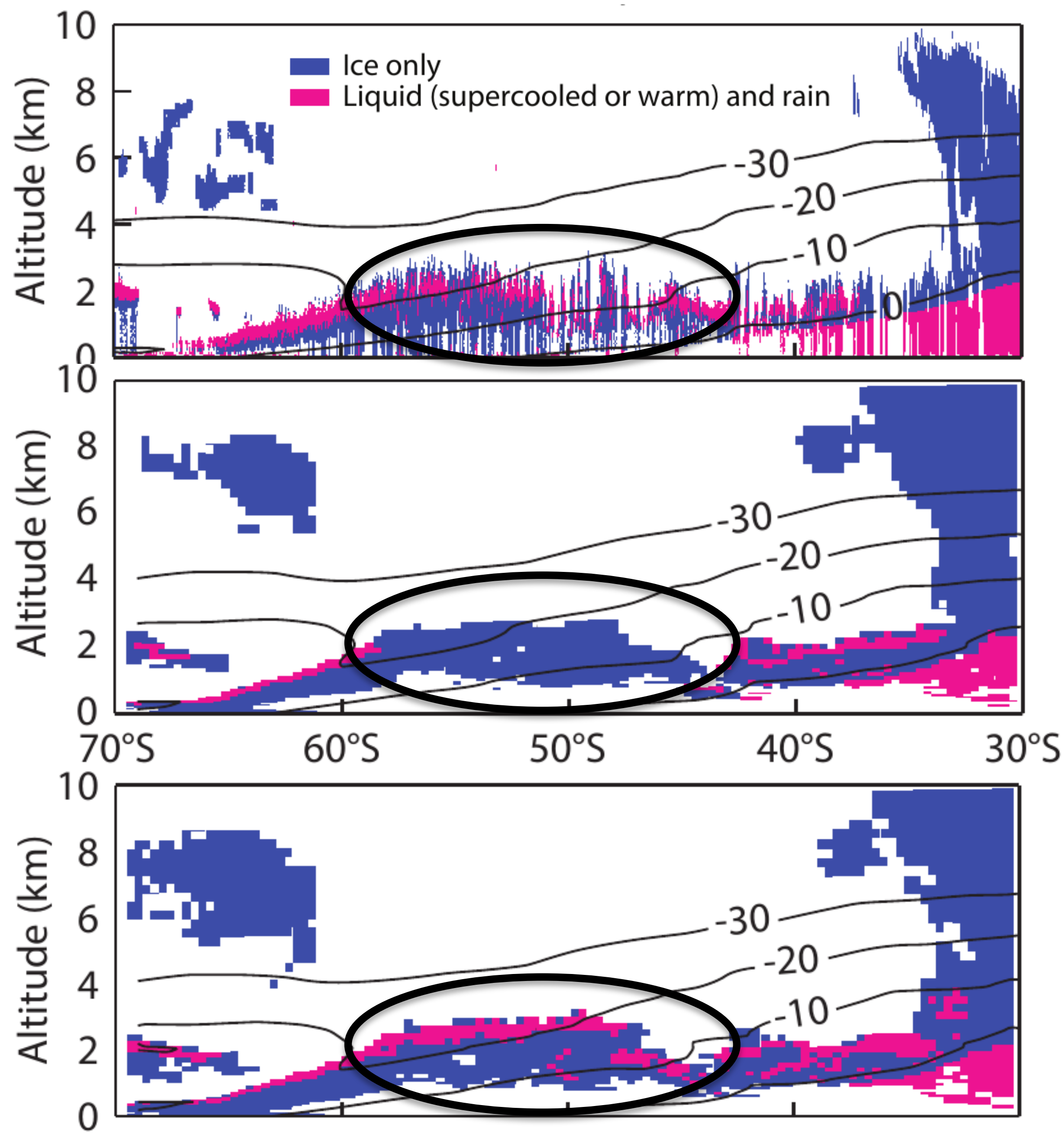


Convection scheme microphysics: Saturation adjustment, autoconversion, detrainment to cloud scheme

Phase = fn (T) from 0 to -23°C

Change to the model convective parametrization to produce SLW at colder temperatures

Supercooled liquid water now present at the tops of convective clouds in cold-air outbreaks



CALIPSO satellite lidar cloud phase

IFS along-track lidar forward modelled cloud phase

IFS with convection producing SLW below 600hPa

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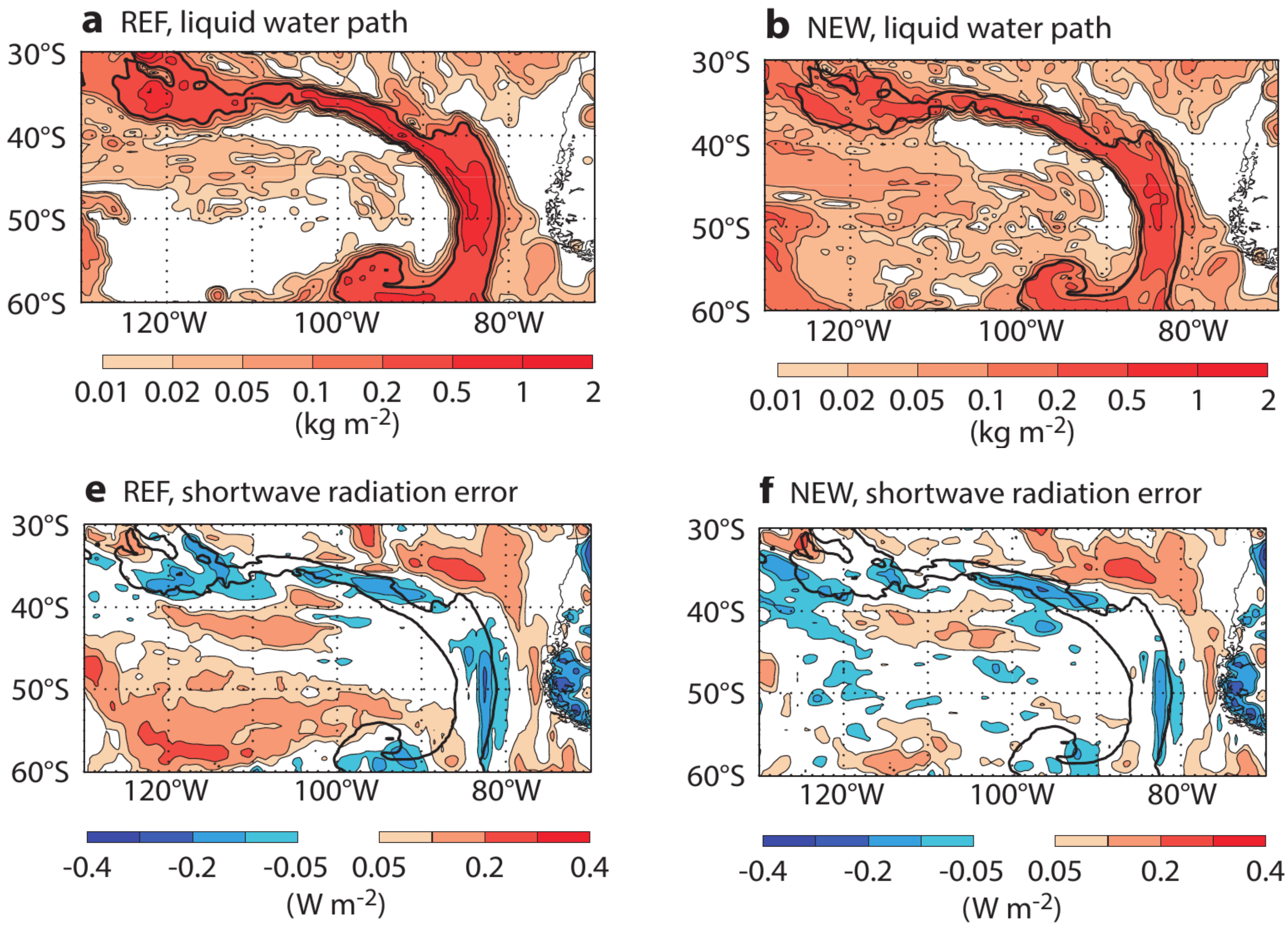
More liquid water path (closer to SSMI/S) and SW radiation dramatically reduced!

24 hour forecast



Forbes et al. 2016
ECMWF Newsletter 146

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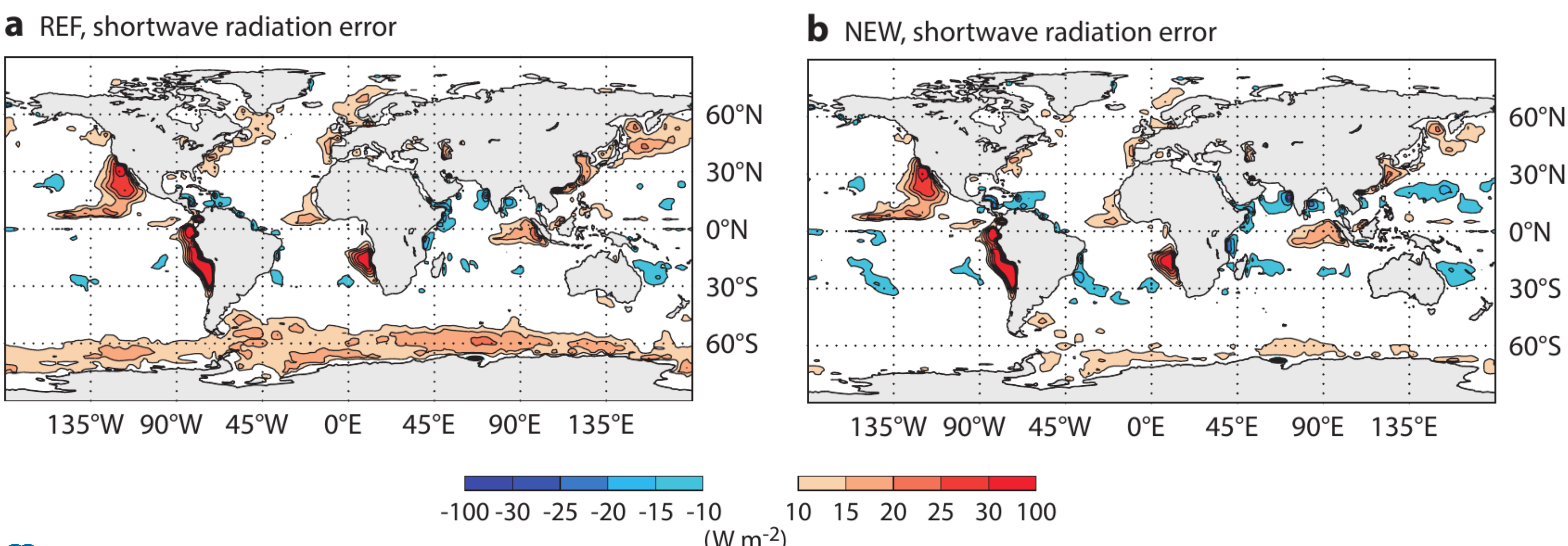
Understanding processes – improving parametrizations Using observation synergy and modelling studies

Example: The Southern Ocean SW radiation bias.

- Synergy of observations from CERES, MODIS, SSMI/S & CALIPSO helped to pinpoint the source of a major error in the IFS
- Improving the parametrization leads to improved forecasts

1 year low res "climate" forecast



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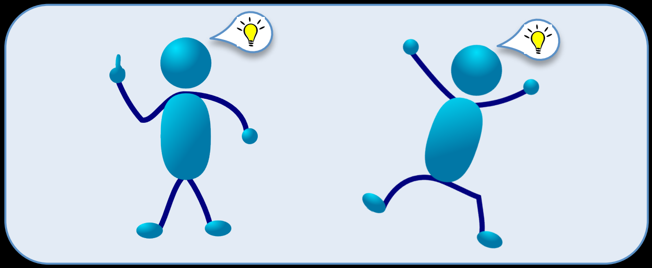
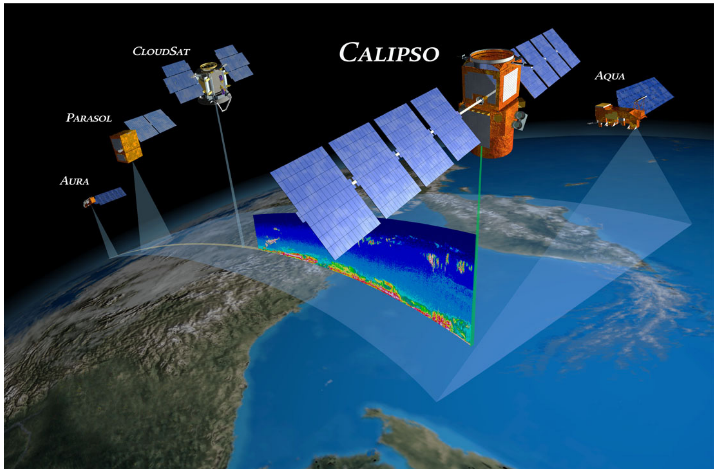


3. Union
(Data assimilation)

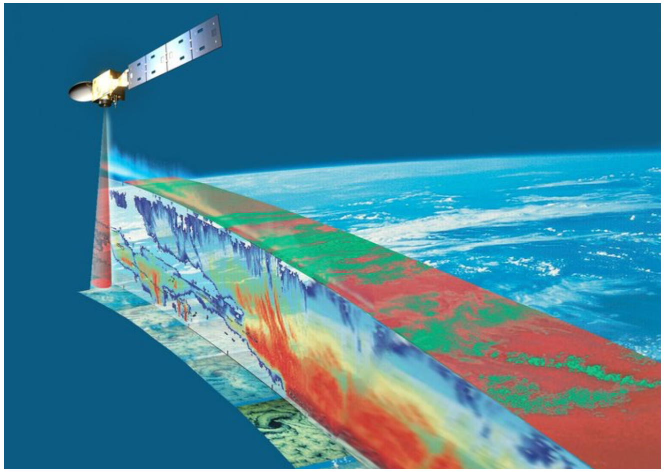
A union of models and observations
Assimilation of active satellite data

- If the model background state is far from the observations, it is very difficult to extract useful information from the data.
- Are the NWP systems good enough for active instruments (radar, lidar) to have a positive impact? Does the data have a positive impact?
- ESA-funded projects at ECMWF over the last few years looking ahead to the launch of EarthCARE and in readiness for assimilating the data into the ECMWF global model.

From CALIPSO-CloudSat to EarthCARE



NASA Langley Research Center



ESA - AOES Medialab

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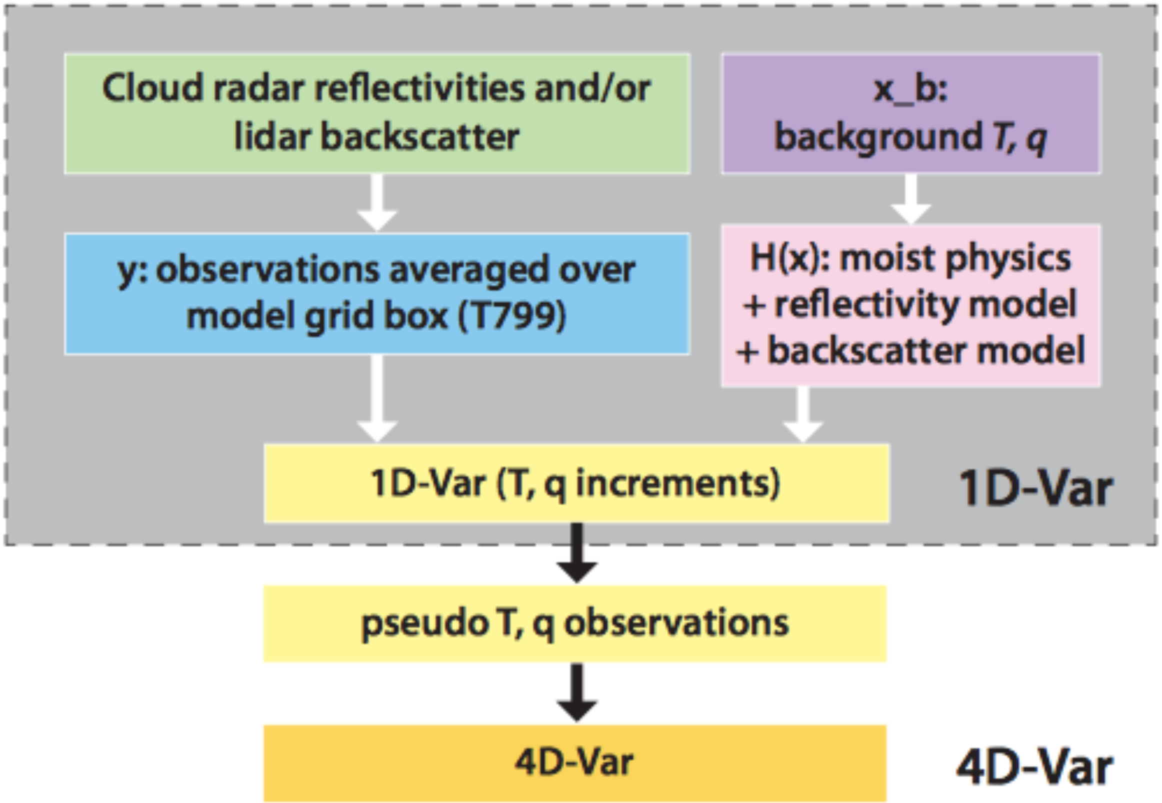
Assimilating CALIPSO–CloudSat data
Janisková et al. (2012), Janisková (2014)

1D+4DVAR

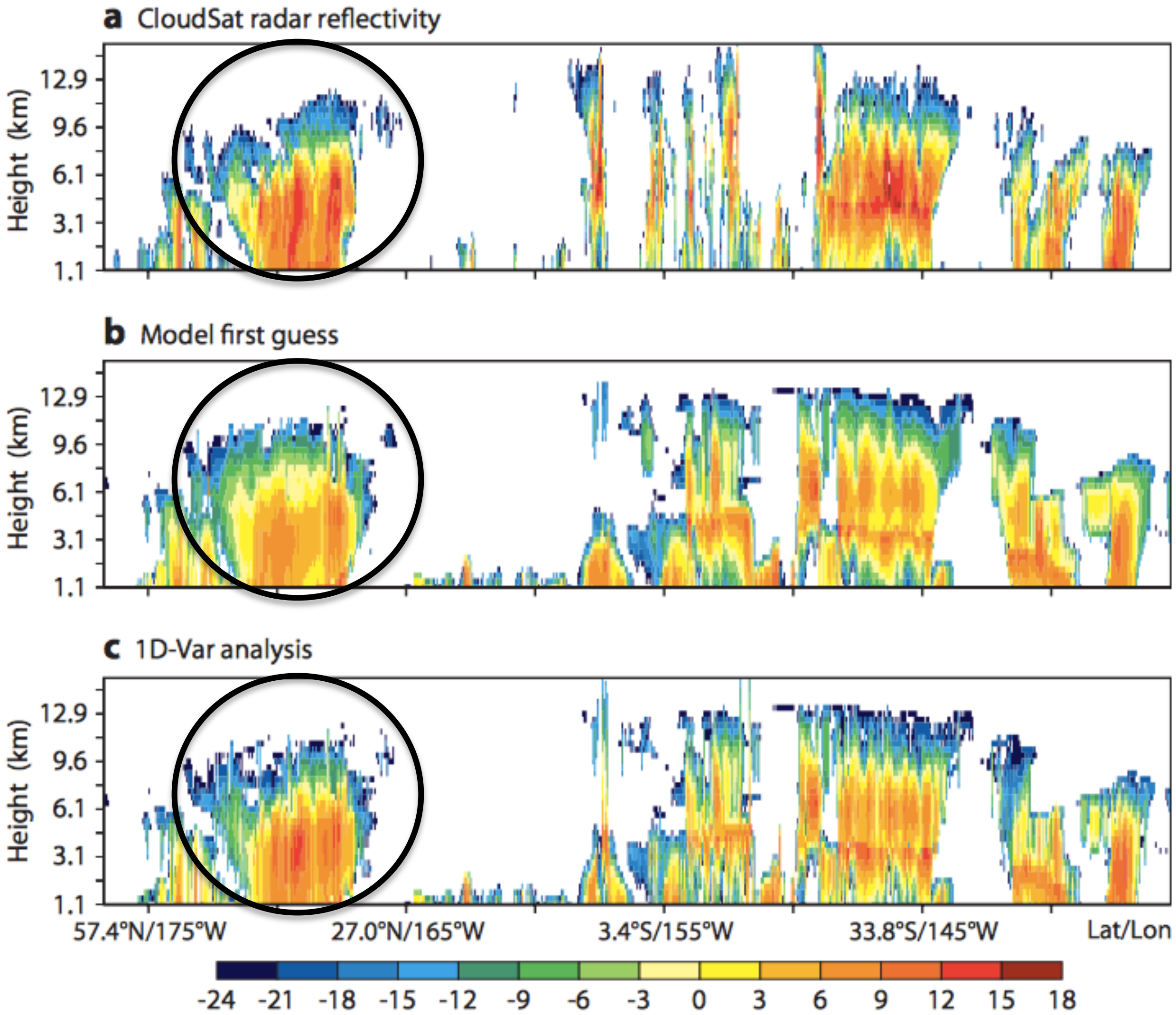


Assimilating CALIPSO-CloudSat data

Janisková (2014)

1DVAR successfully draws model closer to the obs

- 1D-Var analysis of reflectivity, example track
- Greatest impact in front, obs errors large in convection



Assimilating CALIPSO-CloudSat data

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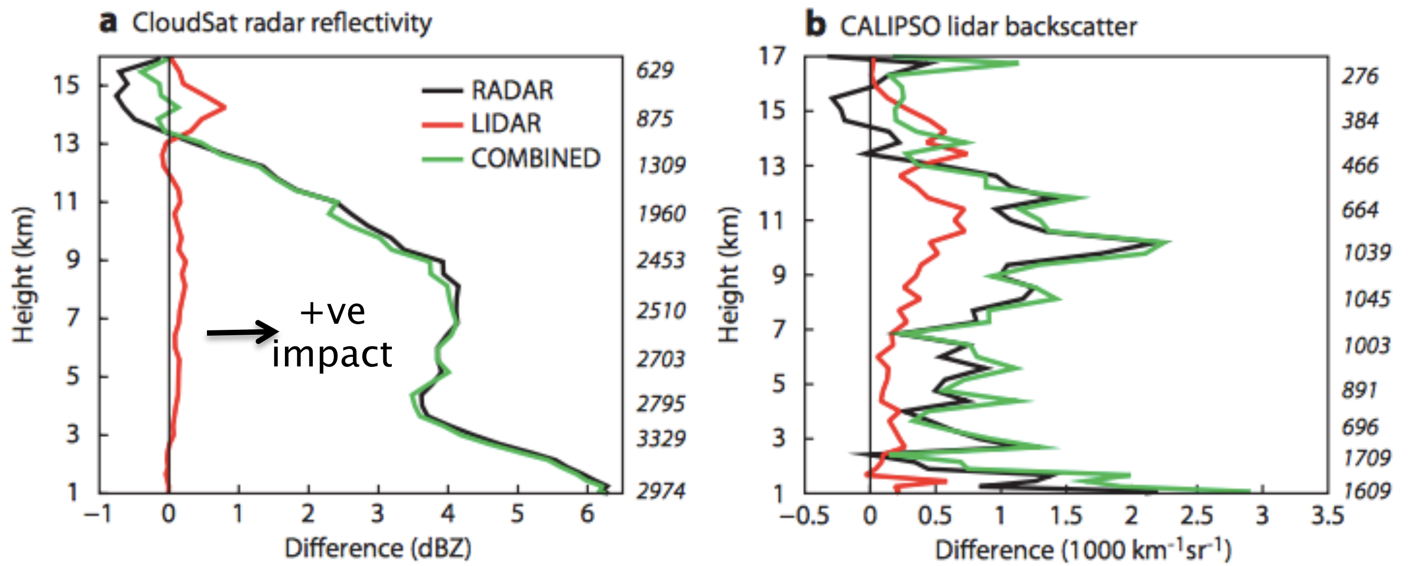
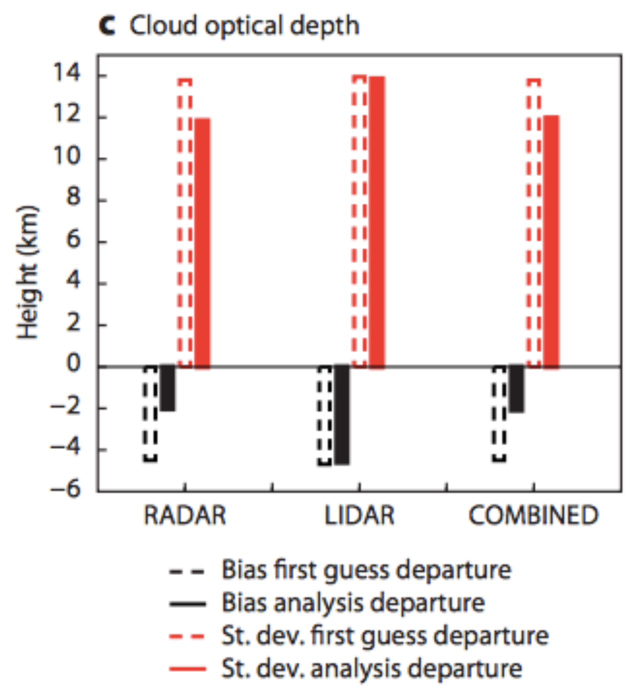




- 1DVAR brings model profile closer to observed reflectivity, lidar backscatter and optical depth (independent)
- Radar has largest impact
- Lidar has impact near cloud top

Assimilating CALIPSO-CloudSat data

Positive impact of 1D+4DVAR on the forecast

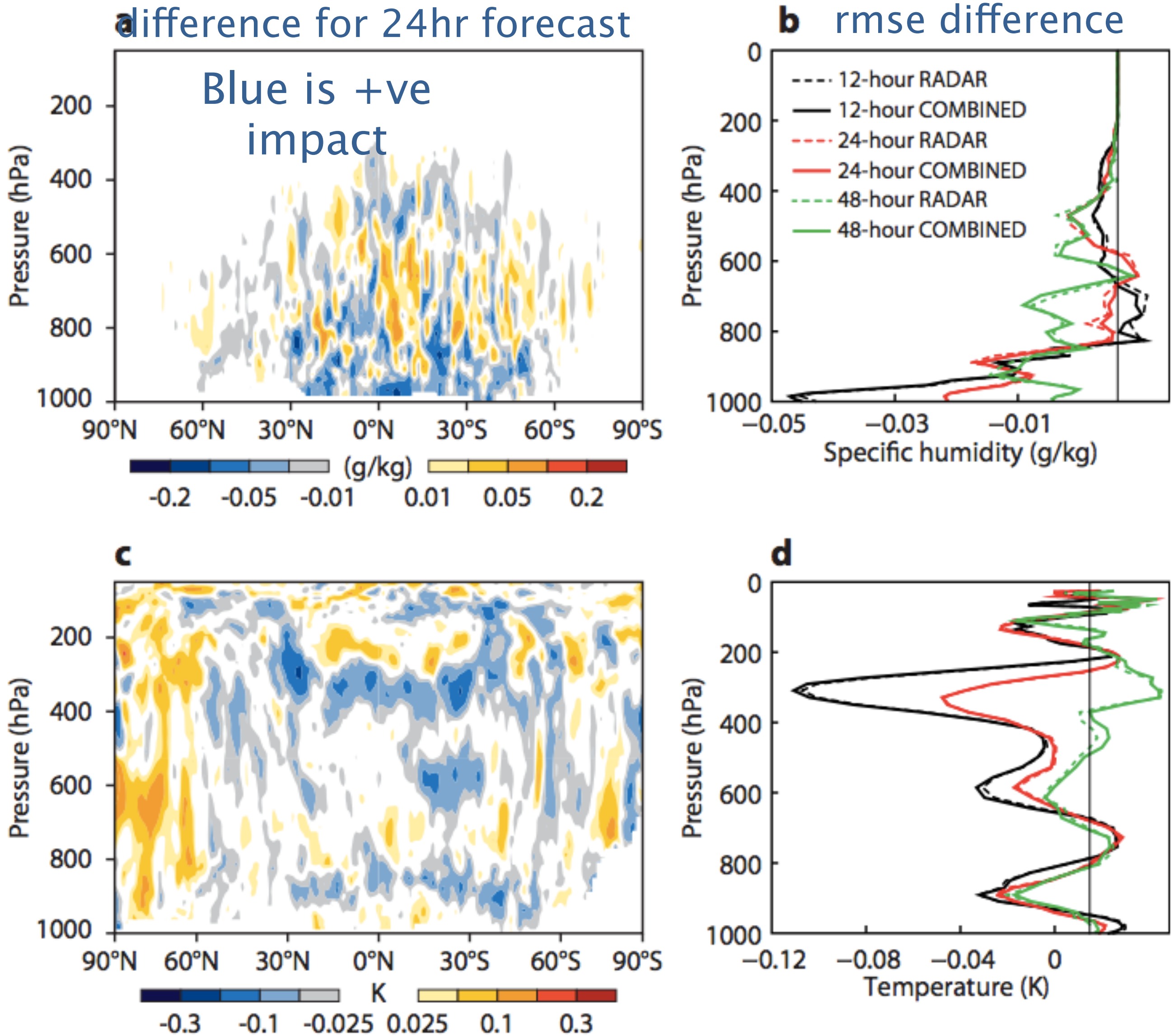
Janisková (2014)

Zonal mean of rmse difference for 24hr forecast

Global mean of T+12,24,28 rmse difference

Specific Humidity

Temperature



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An Unprecedented Confrontation
Global NWP vs CALIPSO-CloudSat

Summary

- Confrontation: CALIPSO & CloudSat have confronted GCMs with an unprecedented level of cloud and precipitation observations.

- Understanding: Multi-sensor observations have helped us to understand processes and how to represent them in models.

- CALIPSO/CloudSat has inspired, and continues to inspire, improvements to parametrizations.

- Union: Models getting closer to the observations. Assimilation of active sensors becoming feasible & beneficial

- 10 years so far and the legacy of CALIPSO/CloudSat for NWP and climate model development continues with vigour…