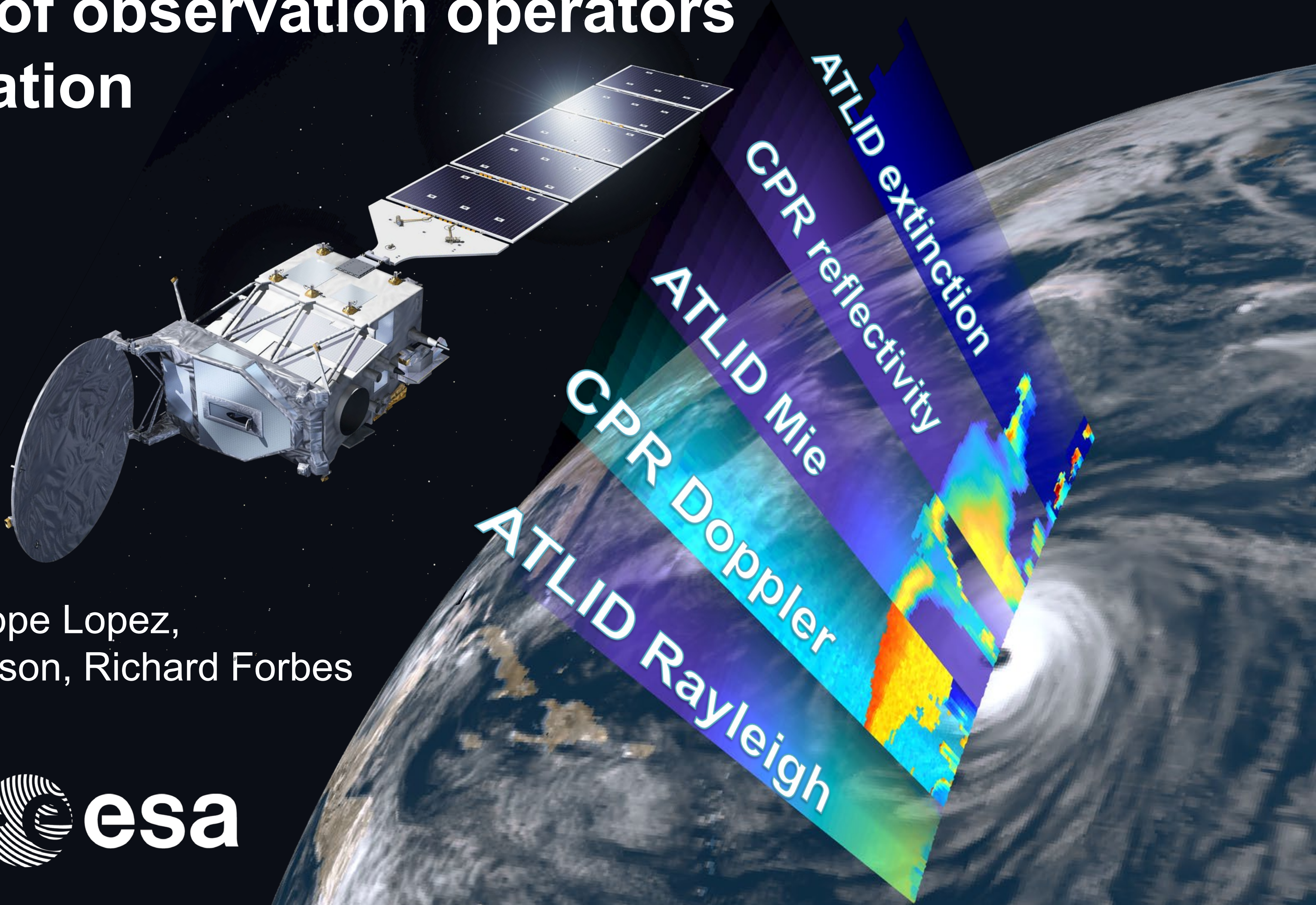
Exploiting the power of EarthCARE synergy through a suite of observation operators for data assimilation



Mark Fielding
Marta Janisková

Thanks: Tobias Wehr, Philippe Lopez,
Robin Hogan, Shannon Mason, Richard Forbes
ECMWF
ESA LPS 26th May 2022

ECMWF
EUROPEAN CENTRE FOR MEDIUM RANGE WEATHER FORECASTS
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High-res observations increasingly important for global NWP

- Reaching critical point of permitting convection in global NWP simulations (Wedi et al., 2020, *JAMES*). Observations at these km scales will be needed to both initialise and improve model.

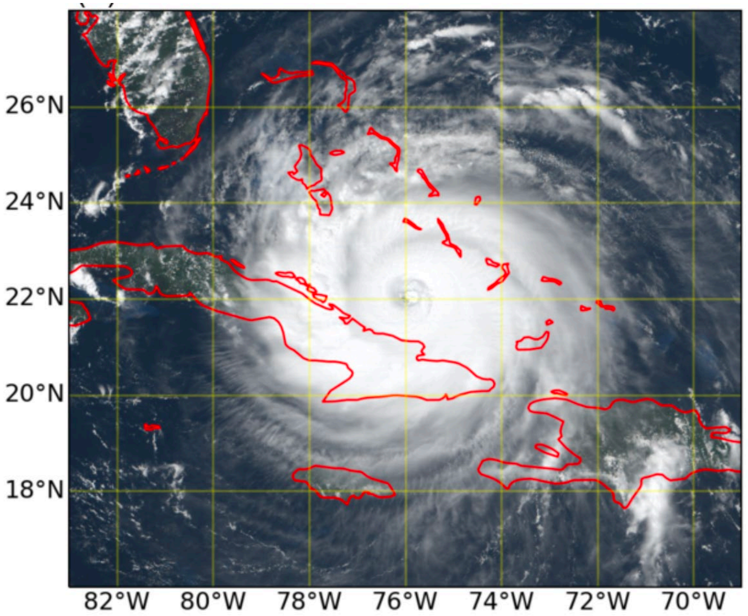
More complex microphysics?

How to initialise?

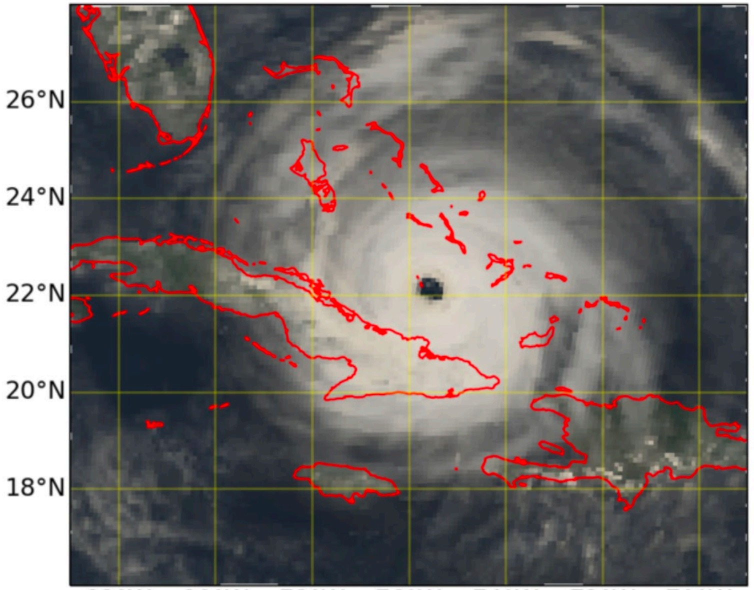
Radiation interactions?

Insufficient convective organisation?

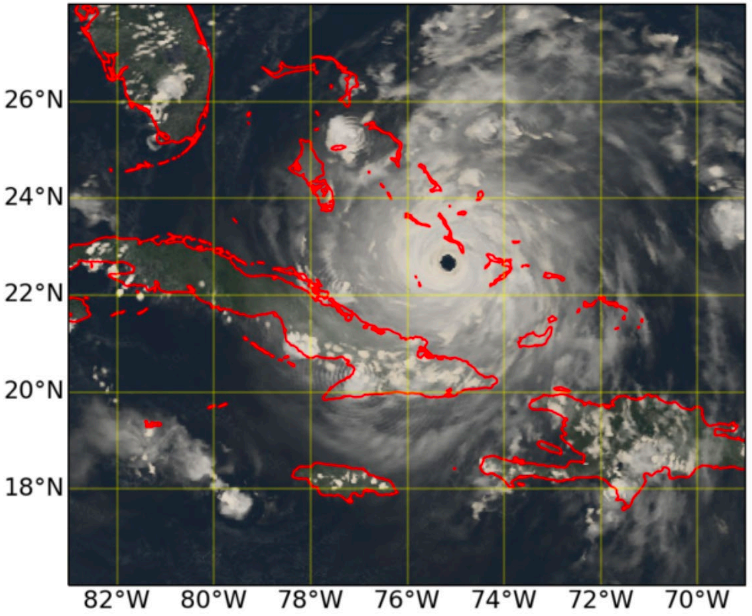
GOES visible imagery



IFS 9 km model imagery



IFS 2.9 km model imagery



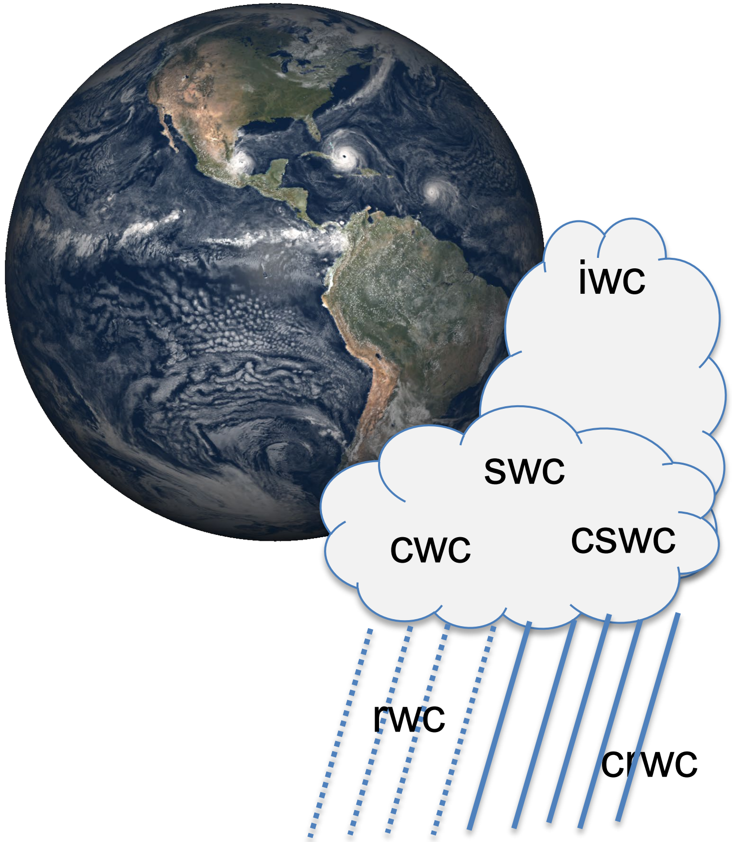
P. Lopez et al., 2022, ECMWF tech memo 892

Sophisticated, well-tuned parameterizations for clouds and convection

Convection permitting paradigm introduces new challenges

Towards a suite of observation operators for EarthCARE within the IFS

ECMWF IFS (Integrated Forecast System) model cloud fields



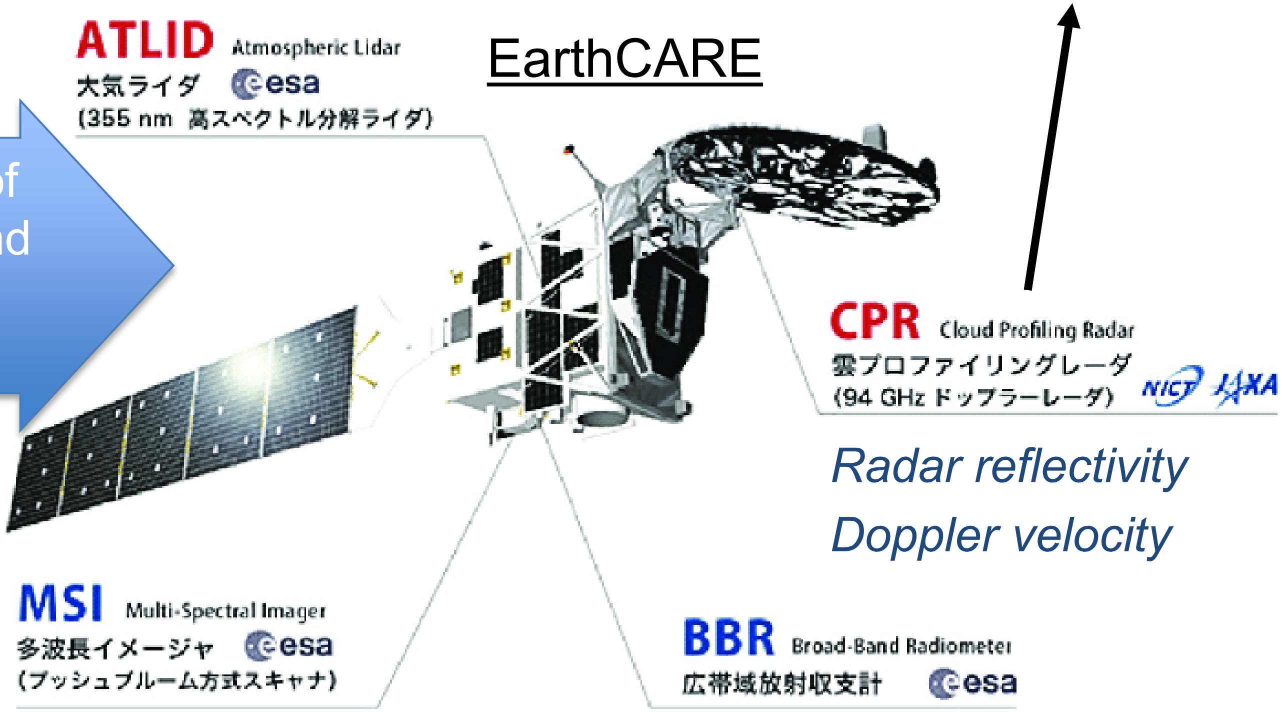
Consistent set of Microphysical and radiative assumptions

Mie backscatter

Rayleigh backscatter → *ZmVar (Di Michele et al., 2012; Fielding and Janisková, 2020)*

Mie extinction

EarthCARE



Radar reflectivity

Doppler velocity

Visible and NIR radiances

MFASIS (Sheck et al., 2016 JSQRT)

FLOTSAM (Hogan, in prep.)

Broadband fluxes

ecRad (Hogan and Bozzo, 2017)

See Liam Steele's poster in C1.06

Using the Jacobian to highlight synergies between EarthCARE observations

- In the ECMWF data assimilation system, tangent linear and adjoint versions of the forward models are used to minimize the 4D-Var cost function.
- Adjoint code provides the Jacobian (sensitivity of the output of the observations operator to its input).
- Comparing the Jacobians of the different EarthCARE observations can highlight synergies between them:

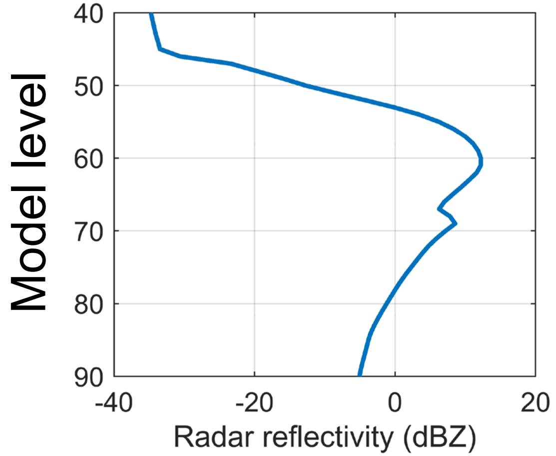
$$\frac{\partial H(x)}{\partial x}$$

Change in simulated observation (e.g., radar reflectivity, lidar backscatter…)

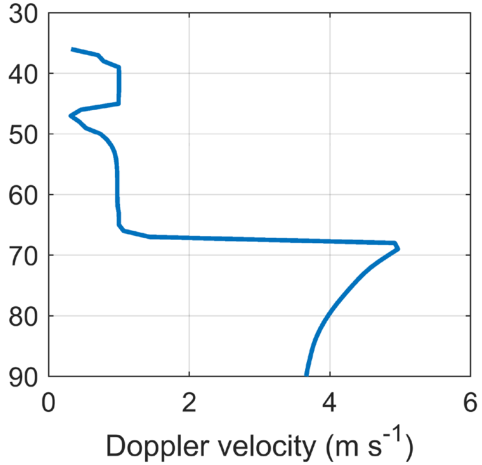
Change in input to observation operator (e.g., rain water content, ice water content, temperature…)

Assimilating Doppler and reflectivity removes attenuation ambiguities

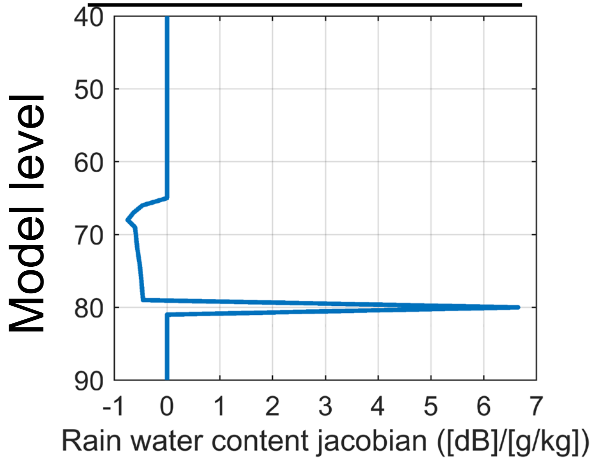
Radar reflectivity profile



Doppler velocity profile

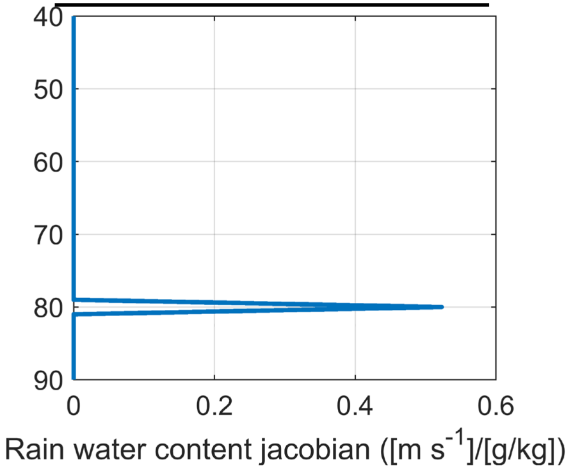


Rain water Jacobian



Sensitivity of radar reflectivity at **model level 80**

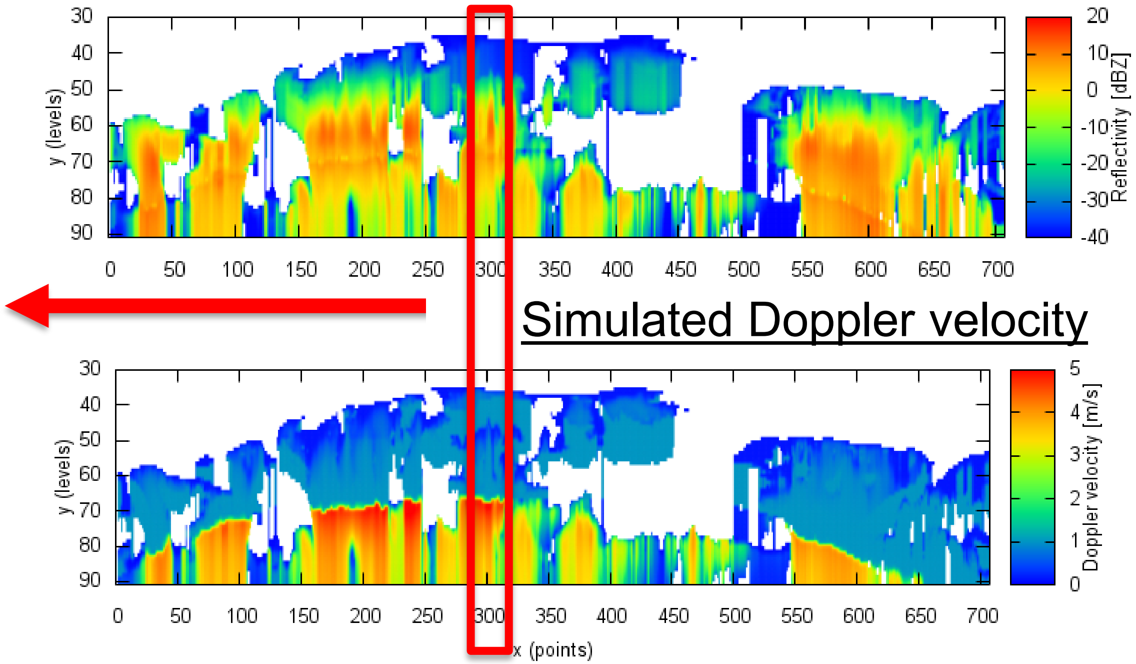
Rain water Jacobian



Sensitivity of Doppler velocity at **model level 80**

Simulated radar reflectivity

Simulated Doppler velocity

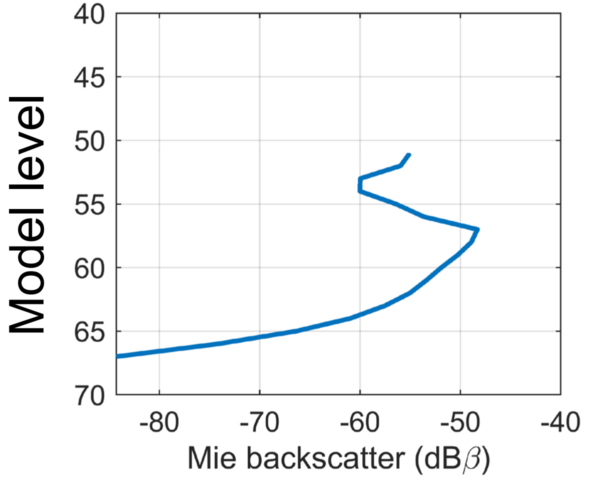


- Radar reflectivity at level 80 can be increased by either reducing rain water content in upper levels, or increasing rain water content at level 80.
- Doppler only sensitive to rain water content at level of observation.

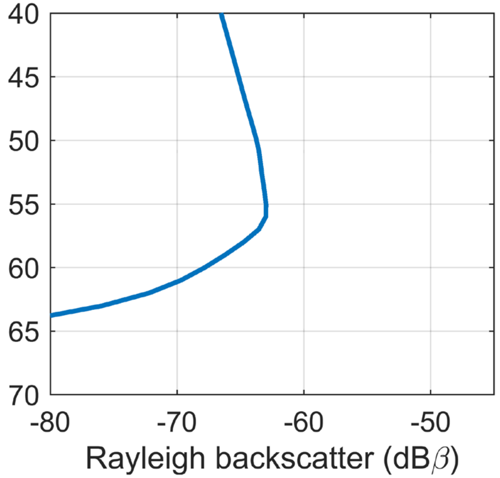
Rayleigh backscatter helps to differentiate between extinction and backscatter

- Jacobian for Extinction analogous to Doppler

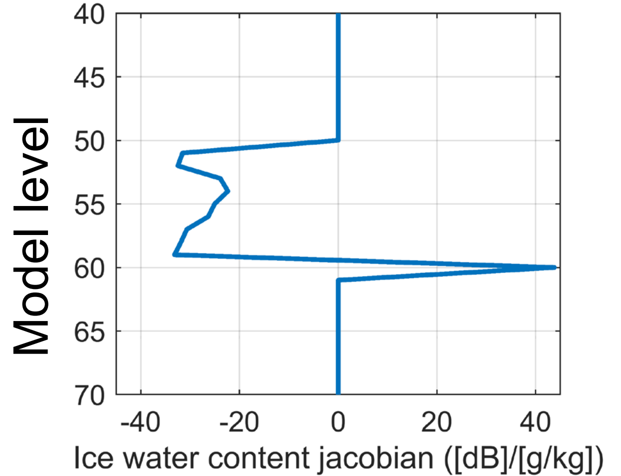
Mie backscatter profile



Rayleigh backscatter profile

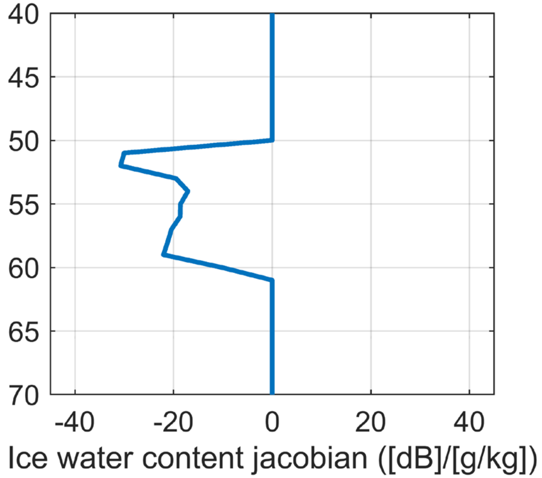


Ice water content Jacobian

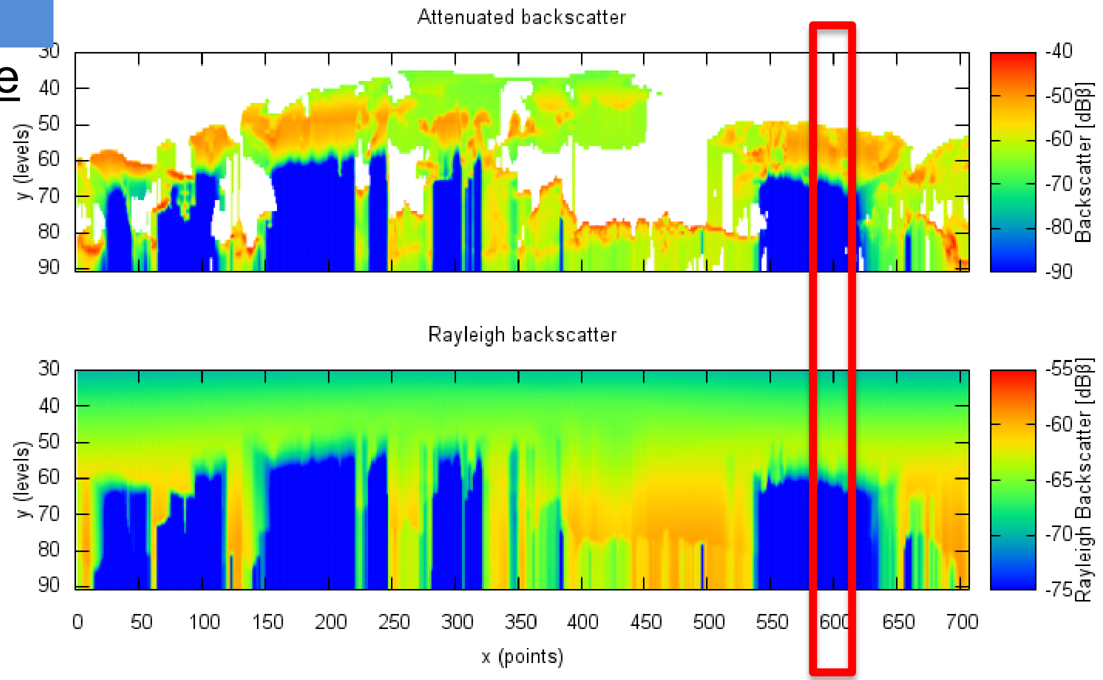


Sensitivity of Mie backscatter at **model level 60**

Ice water content Jacobian



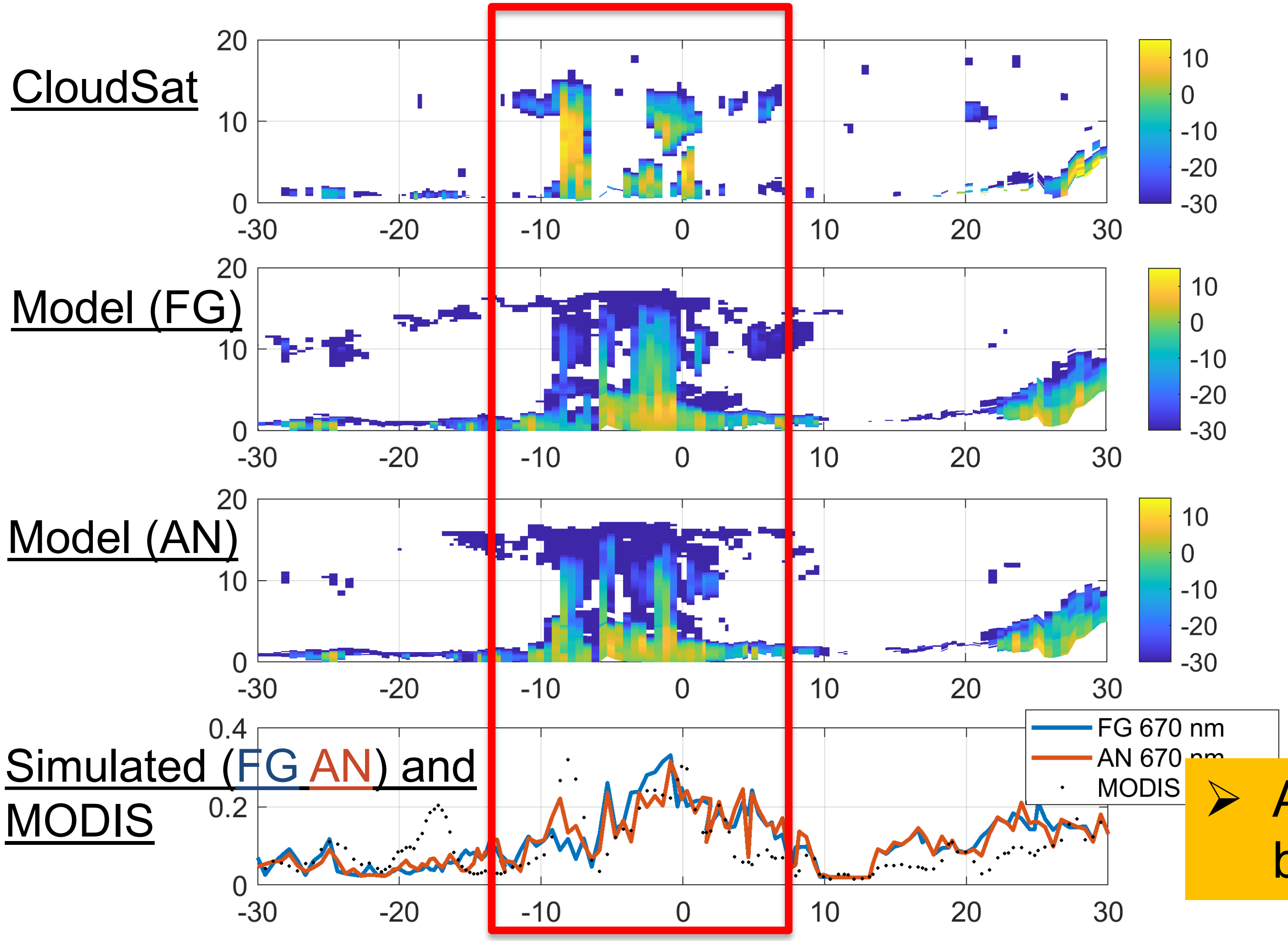
Sensitivity of Rayleigh backscatter at **model level 60**

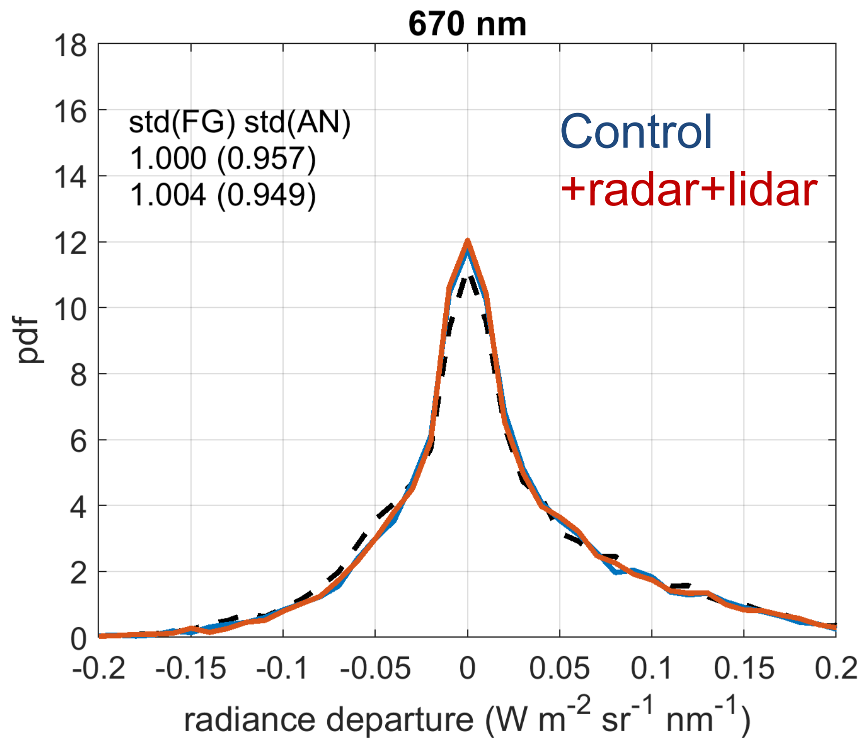


- Mie backscatter at level 60 can be increased by either reducing ice water content in upper levels, or increasing ice water content at level 60.
- Rayleigh backscatter only sensitive to ice water content above level of observation.
- Smoother gradients preferred by 4D-Var!

Verifying assimilation experiments using visible radiances

- Compare simulated visible radiances using FLOTSAM with MODIS observations along A-train track before (FG) and after (AN) assimilation of radar reflectivity and lidar backscatter (see our poster for more details on assimilation experiments)





➢ Assimilating radar reflectivity and lidar backscatter improves fit to visible radiances!

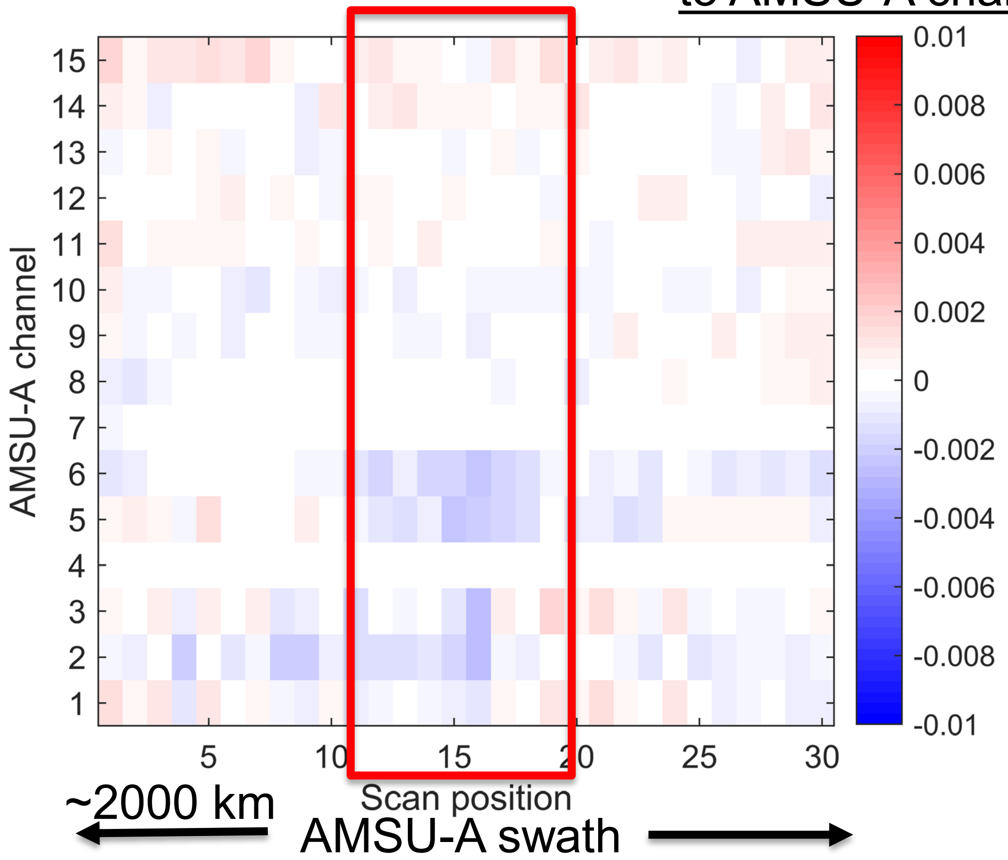
…and also improves fit to *microwave* radiances!

- AMSU-A sensor aboard Aqua provides opportunity to assess impact of radar and lidar on co-located microwave radiances
- Microwave radiances simulated by RTTOV within IFS all-sky framework

Channel	Frequency (GHz)	Peak sensitivity (hPa)
1	23.8	Surface
2	31.4	Surface
3	50.3	Surface
4	52.8	920–810
5	53.596 ± 0.115	650–530
6	54.4	390–320
7	54.94	260–200
8	55.5	170–135
9	$57.29 = f_0$	85–70
10	$f_0 \pm 0.217$	50–40
11	$f_0 \pm 0.3222 \pm 0.048$	25–20
12	$f_0 \pm 0.3222 \pm 0.022$	10
13	$f_0 \pm 0.3222 \pm 0.010$	5
14	$f_0 \pm 0.3222 \pm 0.0045$	3
15	89.0	Surface

Duncan et al., 2022

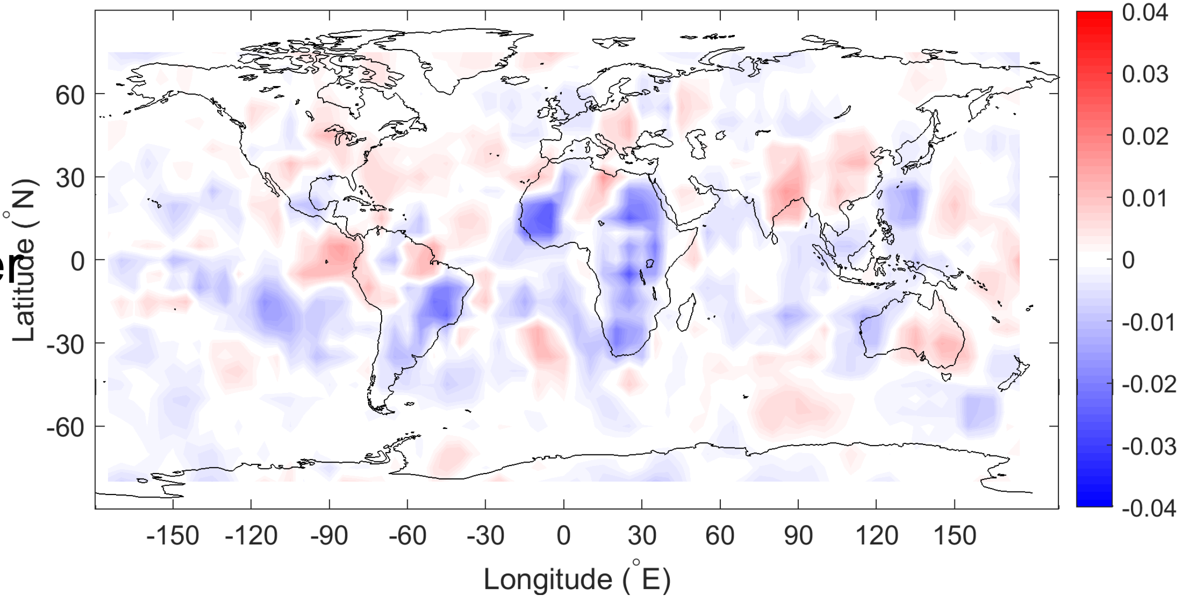
Change in std(AN dep) to AMSU-A channels



Worse fit

Better fit

Change in std(AN dep) of AMSU-A channel 2



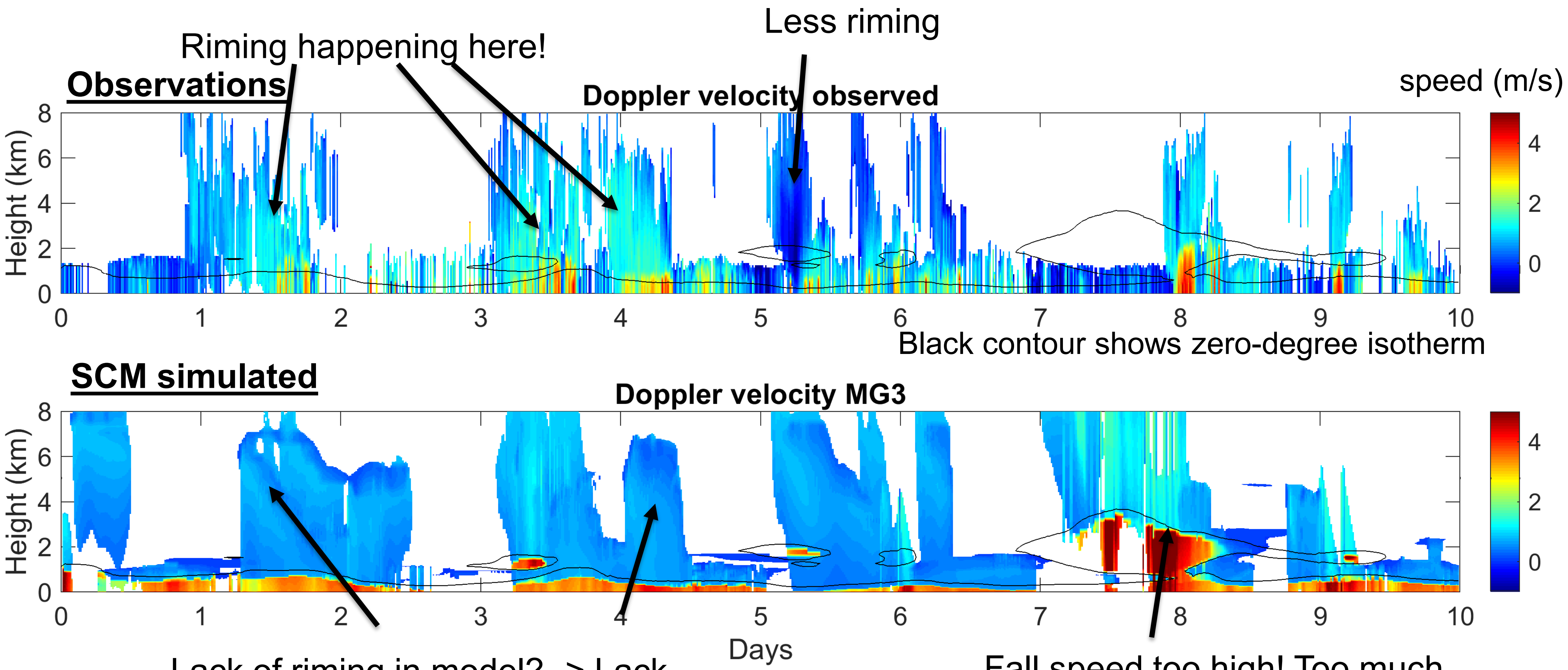
Comparing simulated Doppler velocity with ground-based observations

- Super-cooled liquid clouds have a strong radiative influence, yet difficult to constrain in models, partly due to lack of observations.
- Macquarie Island Cloud and Radiation Experiment (MICRE) observations provide a testbed for simulating ice-phase cloud processes AND evaluating EarthCARE simulators.
- EarthCARE radar simulator placed in IFS single-column model (SCM) to compare performances of single- and double-moment microphysics schemes with MICRE W-band radar (Gettelman et al., in prep)
- **What can comparing observed and simulated Doppler velocity tell us about model processes?**

Macquarie Island – Southern Ocean

Photo: Gregory Stone

Simulating Doppler velocity *appears* to reveal model process deficiencies…



Observations

Riming happening here!

Less riming

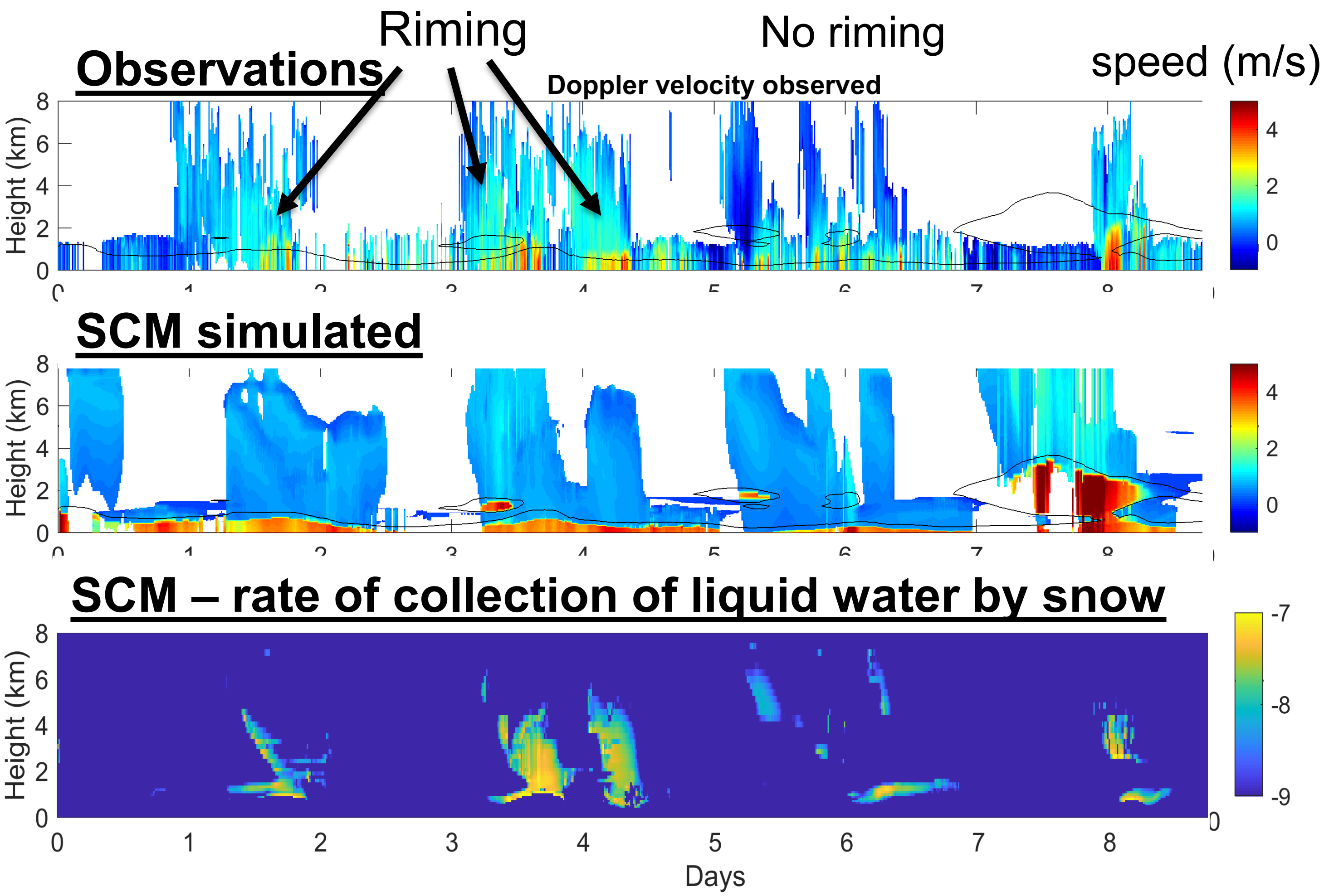
Black contour shows zero-degree isotherm

SCM simulated

Lack of riming in model? -> Lack of super-cooled liquid water?

Fall speed too high! Too much rain?

But, model *does* represent collection of super-cooled liquid cloud by water



Observations

Riming

No riming

SCM simulated

SCM – rate of collection of liquid water by snow

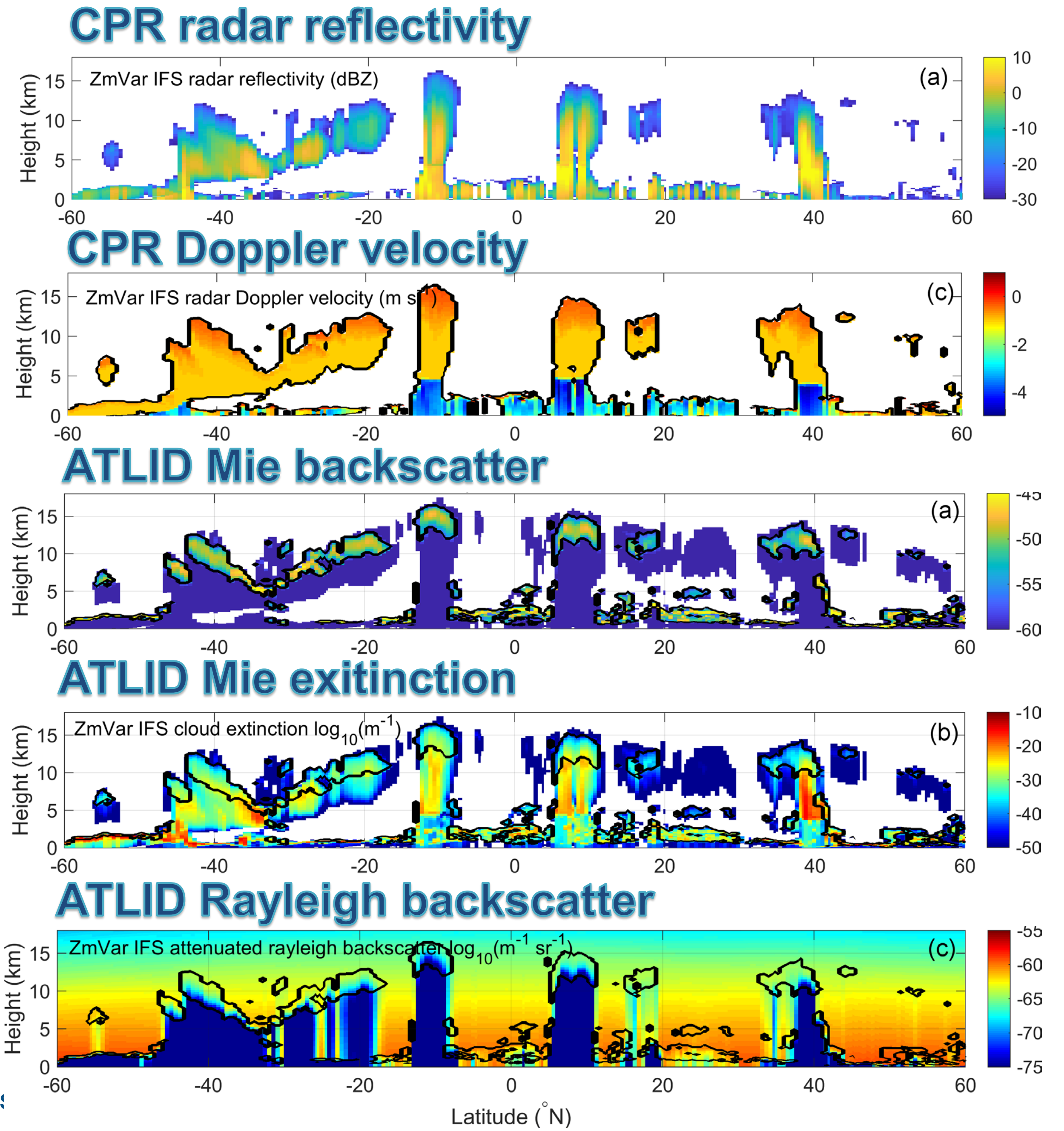
To simulate the Doppler velocity of ice-phase particles more effectively, more complexity is required, e.g.:

- **Additional hydrometeor species** required for rimed snow/graupel (e.g., P3 scheme; Morrison and Milbrandt 2015) or can we diagnose 'density factor'? (see Mason et al., 2018).
- **Physical representation of melting process** must be included for realistic Doppler simulations. (Note: melting *is* represented in IFS microphysics scheme)

➢ Not representing increased fall-speed of rimed ice particles

Summary

- A suite of observation operators for simulating EarthCARE within IFS is now available.
- If assimilated, Jacobian of observation operators show Doppler velocity and Rayleigh backscatter should complement radar reflectivity and Mie backscatter.
- Assimilating radar reflectivity and lidar backscatter improves model analysis fit to radiation observations across the spectrum.
- To make Doppler velocity observations tractable for direct model evaluation, need to represent variations in fall-speeds from microphysical processes.


CPR radar reflectivity

CPR Doppler velocity

ATLID Mie backscatter

ATLID Mie exitinction

ATLID Rayleigh backscatter