Parameterization of 3D SW radiative effects of clouds: Evaluation against observations and high resolution models

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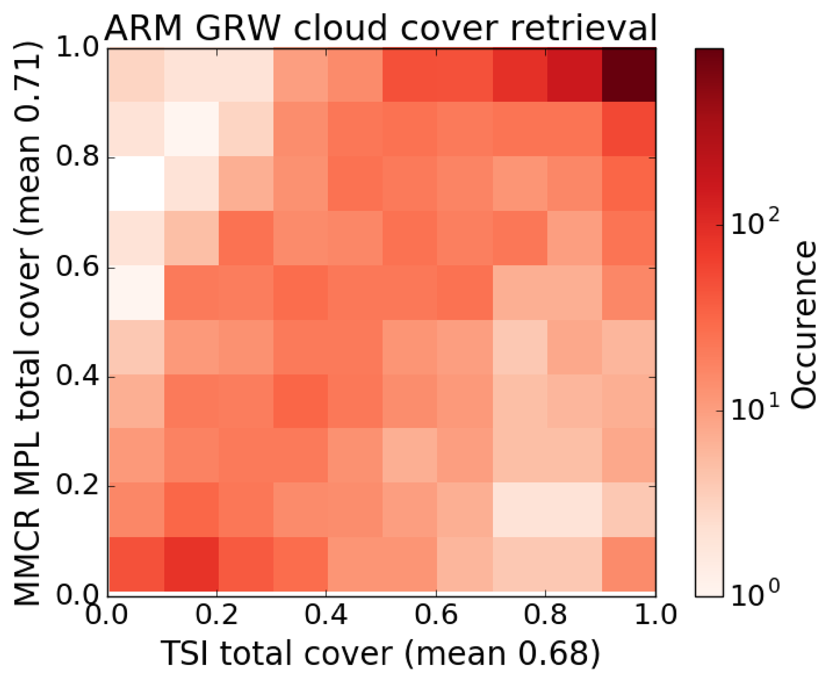
Introduction & Objectives

- 3D interactions between clouds and radiation have the potential to feedback on circulations, temperatures and the energy budget
- We need to take them into account in the radiation schemes, in cloud resolving, numerical weather prediction and climate models
- SPARTACUS is a new solver for 3D effects available in the ECMWF radiation scheme, ecRad. We want to test it with observations.

How can we assess the parameterizations of 3D effects?

1. We use surface radiation and cloud **observations** as a reference
2. to study the dependence of **direct/diffuse partition** on solar zenith angle (SZA), total cloud cover (TCC) & 3D effects in low-cloud situations.
3. We also use **cloud profiles retrievals** embedded in IFS profiles as an input to ecRad to eliminate cloud bias from the diagnosis
4. and analyze the 3D radiative effects of clouds on the ratio.

1. Ground-based observations: radiation and clouds



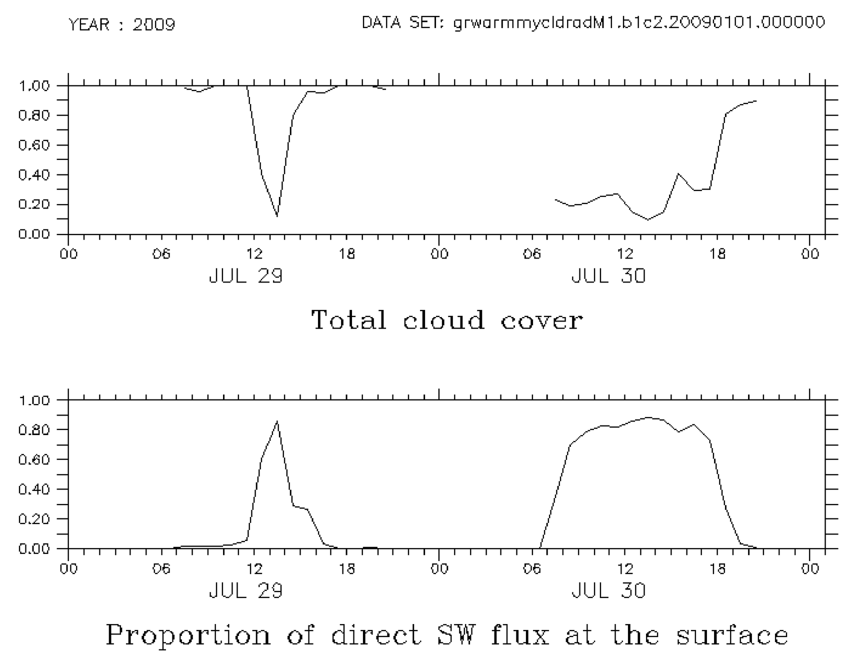
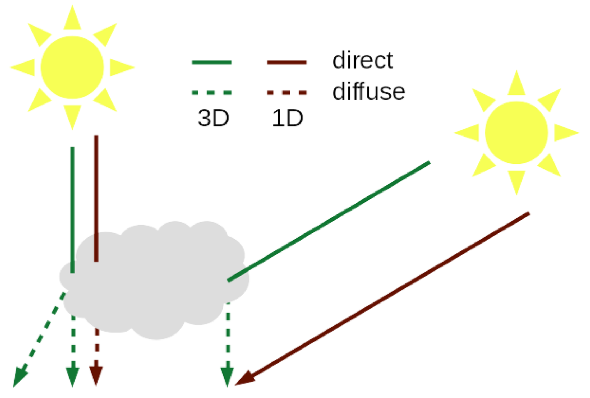


Figure: Left: Discrepancies between observed TCC in low-cloud situations, seen from ground-based total sky imager (TSI) (data from ARM discovery, GRW, 2009-2010) and a combination of Millimeter-wave Cloud Radar (MMCR) and Micropulse Lidar (MPL) (data from Cloudnet, Illingworth et al. 2007) on Graciosa Island. Right: Observed TCC and direct-to-global fluxes ratio at the surface during two summer days over the Graciosa Island. The direct radiation is measured by a pyrheliometer of viewing angle 5.7^o while the total radiation is measured by a pyranometer.

2. The direct / diffuse partition

The **direct / diffuse partition** is relevant to a number of applications (solar energy, vegetation). The relative amount of direct radiation decreases with **solar angle** and **cloud cover**. It is also driven by 3D radiative effects of clouds, that relate to **transport through clouds sides**:



Scattering through cloud edges: diffuse 3D > diffuse 1D

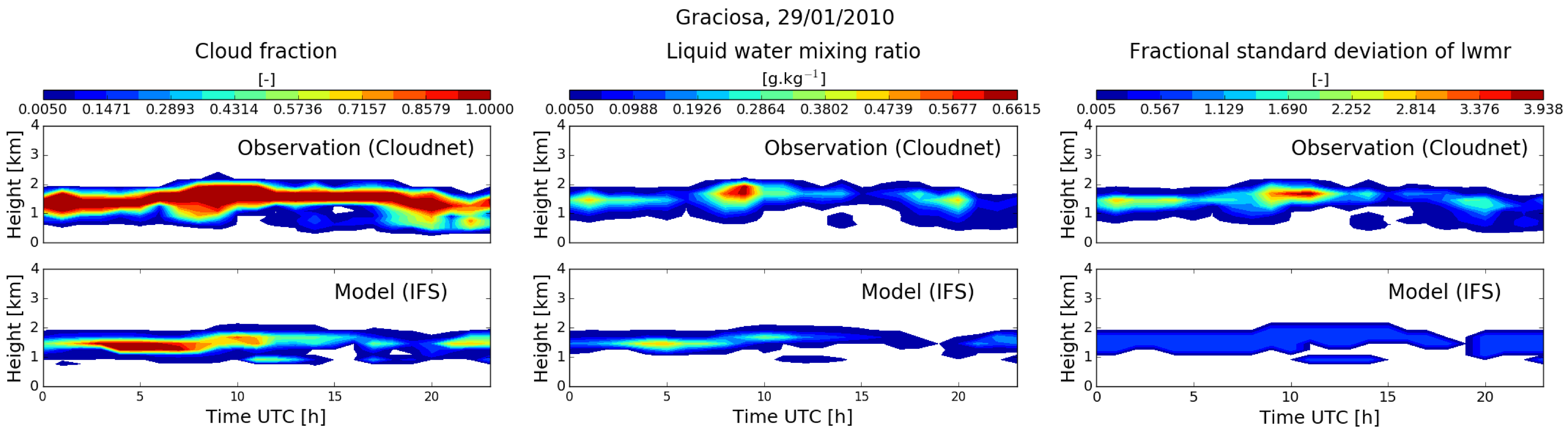
Interception of direct beam: direct 3D < direct 1D

3D effects of clouds: **ratio 3D < ratio 1D**

A better representation of the 3D transport should allow a better approximation of the direct-to-total ratio.

3. The composite profiles

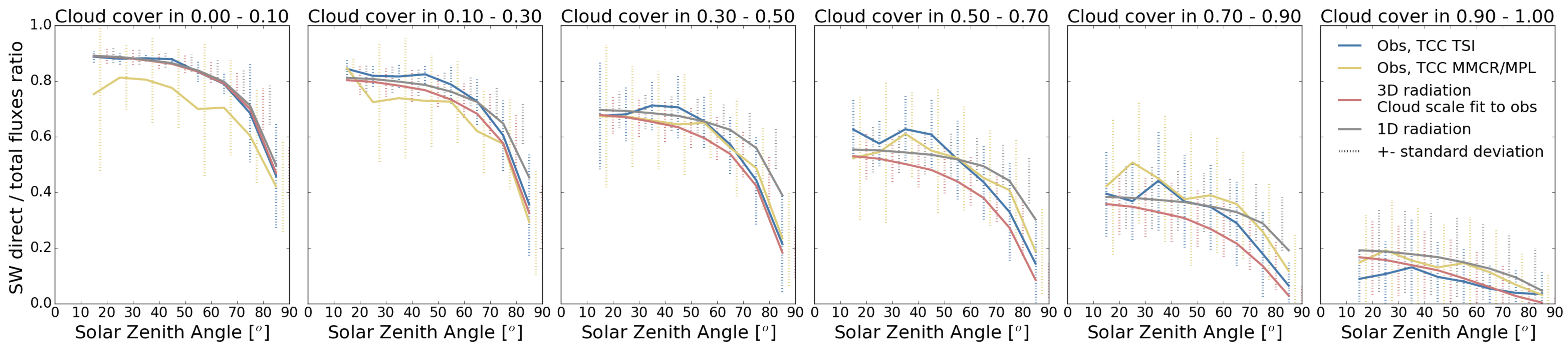
Differences between modeled and observed clouds can bias the evaluation of the parameterization of the 3D transport of radiation in cloudy atmospheres. We use **retrieved cloud profiles** from Cloudnet (cloud fraction, liquid water content, standard deviation of liquid water content) as an input to **off-line radiation scheme** to eliminate the cloud bias and isolate the transport bias.



4. Is there observational evidence for the 3D effects ?

The mean direct-to-global fluxes ratio is plotted against SZA in 5 increasing TCC bins, with two curves for observations (blue and yellow) and two for models (red and gray). In the model runs, the delta scaling has been adapted to match the pyrheliometer definition of direct flux: incoming radiation ± 2.85^o around the sun beam.

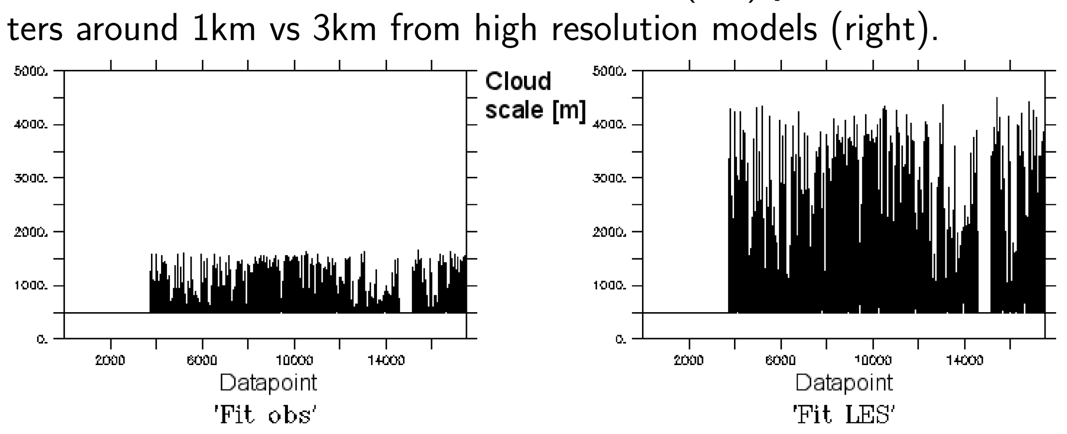
Observed and composite mean ratio. Impact of 3D radiation.



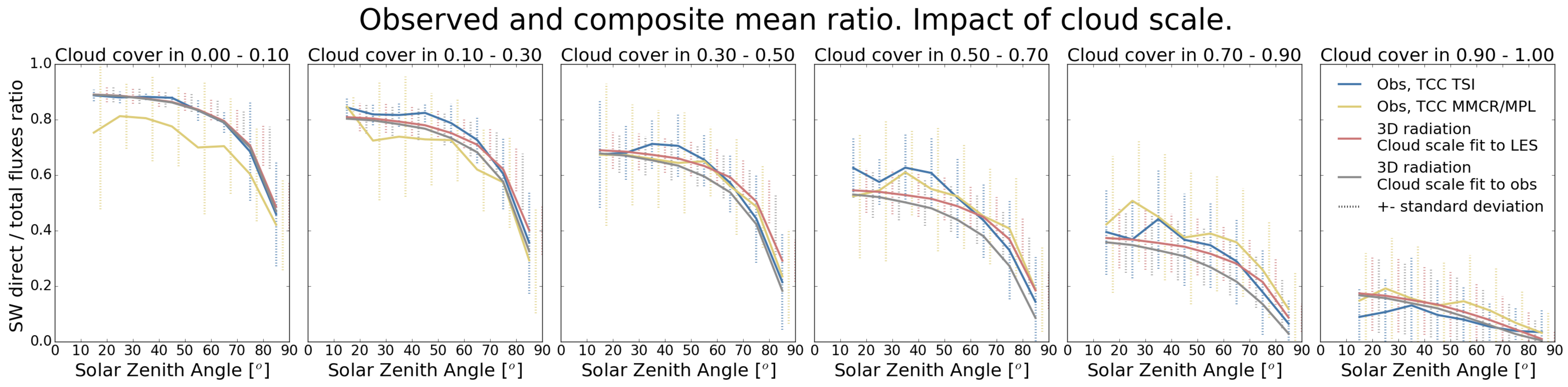
As MMCR/MPL sees a smaller portion of the sky than the TSI, MMCR/MPL retrievals of TCC are underestimated in near clear cases and overestimated in near overcast cases, which explains most of the spread between the blue and yellow curves.
As expected, taking the 3D effects into account yields a smaller direct-to-global ratio for all SZA and TCC ranges. The greatest impact is found for SZA > 60^o, TCC > 0.3.

Although the observations are better fitted with 3D effects, there is still some room for improvement. The main parameter involved in 3D effects is the **cloud scale**: bigger clouds yield less interface between clear and cloudy regions i.e. 3D effects are less important. A parameterization of cloud scale was developed with dependency on height and cloud fraction.

Figure: Cloud scale parameterization applied to Cloudnet profiles. Parameterization derived from observations (left) yields cloud diameters around 1km vs 3km from high resolution models (right).



Observed and composite mean ratio. Impact of cloud scale.



Bigger clouds seem to yield a better approximation of the mean direct-to-total ratio, although smaller clouds were observed. An effect that was shown to have the same impact as increasing the cloud scale (i.e. decreasing 3D effects) is the neighboring effect i.e. interception of radiation by neighboring clouds.

Conclusions

We propose the **direct/diffuse partition as a new metric to evaluate parameterizations of 3D radiative effects of low clouds**:

- We assume: **3D transport** of SW radiation affects the **direct/total ratio**.
- We use: **observed profiles** to separate cloud bias from radiation bias and **parametrized 3D effects** in a 1D radiation scheme.
- We examine: whether direct/ diffuse flux **observations** provide evidence for 3D effects and whether they can **validate 3D radiation calculations**.
- We find: that **parameterizing 3D effects leads to better estimating direct/diffuse partition of SW fluxes**, with impact of cloud scale.

References

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