Using direct and diffuse surface solar flux observations to test the interaction of boundary-layer clouds with radiation in the IFS

Najda Villefranque[1,2], R.J. Hogan[3], M. Ahlgrimm[3], M. Fielding[3]

[1]CNRM (Meteo France / CNRS), [2]LAPLACE (Universite Toulouse III), [3]ECMWF

June 1, 2018

Outline

Introduction

Observations and IFS

Removing first order biases

The 3D radiative effects of clouds

Conclusions

Briefly introducing myself

- PhD student, France: 3D radiative effects of boundary layer clouds

Briefly introducing myself

- PhD student, France: 3D radiative effects of boundary layer clouds
- CNRM (Meteo France & CNRS), **Fleur Couvreux** and team
  atmosphere, boundary layer, clouds, Large Eddy Models

Briefly introducing myself

- PhD student, France: 3D radiative effects of boundary layer clouds
- CNRM (Meteo France & CNRS), **Fleur Couvreux** and team
  atmosphere, boundary layer, clouds, Large Eddy Models
- LAPLACE (Universite Toulouse III), **Richard Fournier** and team
  physics, radiation, Monte Carlo, integral formulation

Briefly introducing myself

- PhD student, France: 3D radiative effects of boundary layer clouds
- CNRM (Meteo France & CNRS), **Fleur Couvreux** and team
  atmosphere, boundary layer, clouds, Large Eddy Models
- LAPLACE (Universite Toulouse III), **Richard Fournier** and team
  physics, radiation, Monte Carlo, integral formulation
- Tools Large Eddy Simulations (LES) outputs → input for a 3D Monte Carlo radiation solver

Briefly introducing myself

- PhD student, France: 3D radiative effects of boundary layer clouds
- CNRM (Meteo France & CNRS), **Fleur Couvreux** and team
  atmosphere, boundary layer, clouds, Large Eddy Models
- LAPLACE (Universite Toulouse III), **Richard Fournier** and team
  physics, radiation, Monte Carlo, integral formulation
- Tools Large Eddy Simulations (LES) outputs → input for a 3D Monte Carlo radiation solver

- Objective **Better understand** cloud - radiation interactions, **support development and assessment** of 3D radiation schemes

Back to direct / diffuse

Direct and diffuse fluxes are

- Often available in surface **observations**
- Available in the **IFS** and offline radiation scheme, **ecRad**
- Strongly affected by **clouds** and aerosols

$\Rightarrow$ **Can we get information out of it?**

Back to direct / diffuse

Direct and diffuse fluxes are

- Often available in surface **observations**
- Available in the **IFS** and offline radiation scheme, **ecRad**
- Strongly affected by **clouds** and aerosols

⇒ Can we get information out of it?

- On how **cloud - radiation interactions** affect the partition?
- On the **IFS skill in forecasting** this partition?
- On the key **ingredients to improve** this forecasting?

Outline

Introduction

Observations and IFS

Removing first order biases

The 3D radiative effects of clouds

Conclusions

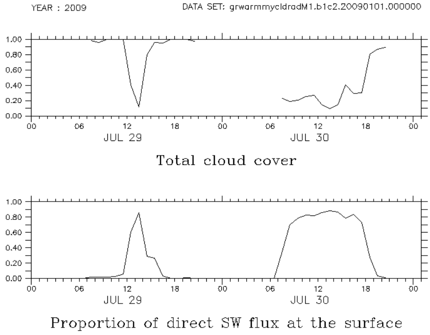
The observations

- ARM Mobile Facility May 2009 - December 2010 Graciosa, Azores, *Clouds, Aerosol, and Precipitation in the Marine Boundary Layer*

'[...] ideal for sampling the transition from an **overcast stratocumulus regime** in the spring to the **broken trade cumulus** regime in the summer' (arm.gov)

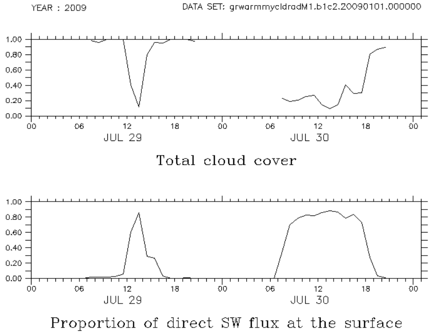
The observations

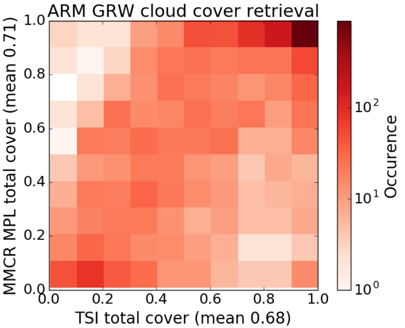
- ARM Mobile Facility May 2009 - December 2010 Graciosa, Azores, *Clouds, Aerosol, and Precipitation in the Marine Boundary Layer*
- ARM products : **SW down direct and total** [radflux], **total cloud cover** estimate from total sky imager (tsi) [tsiskycover]



The observations

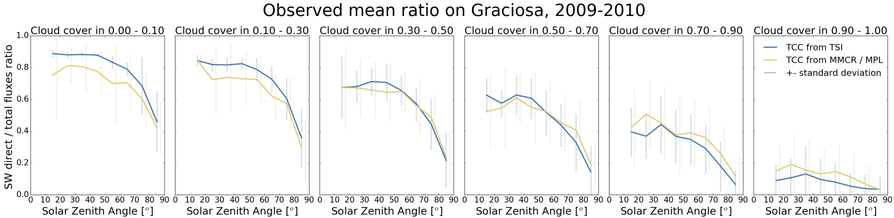
- ARM Mobile Facility May 2009 - December 2010 Graciosa, Azores, *Clouds, Aerosol, and Precipitation in the Marine Boundary Layer*
- ARM products : **SW down direct and total** [radflux], **total cloud cover** estimate from total sky imager (tsi) [tsiskycover]
- Cloudnet data : **total cloud cover** estimate from radar / lidar





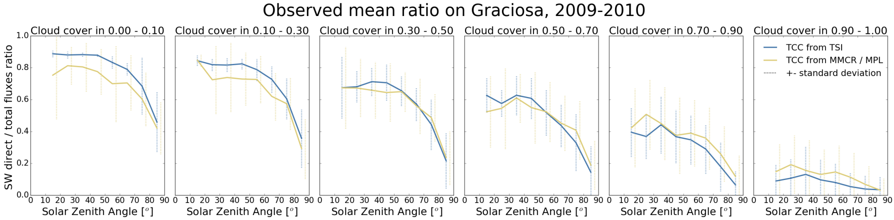
The observed direct to total ratio

As a function of solar zenith angle (SZA) and total cloud cover (TCC) for low-cloud situations only



The observed direct to total ratio

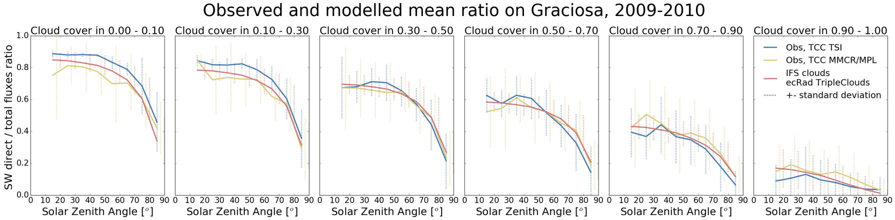
As a function of solar zenith angle (SZA) and total cloud cover (TCC) for low-cloud situations only



Ratio dependence on SZA is noisier when using radar lidar TCC

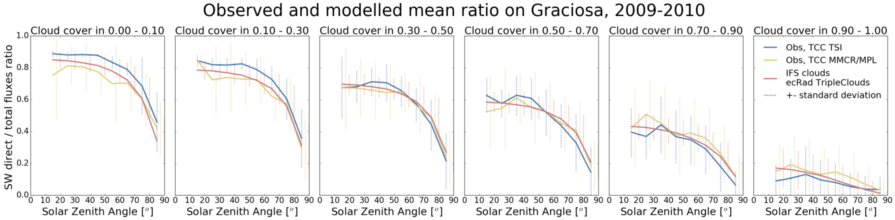
The IFS direct to total ratio

Offline ecRad similar to operational (TripleClouds, exp-ran, FSD 0.75) on **DDH profiles** extracted from the operational HRES model with CAMS aerosol climatology, on **Graciosa 2009-2010**



The IFS direct to total ratio

Offline ecRad similar to operational (TripleClouds, exp-ran, FSD 0.75) on **DDH profiles** extracted from the operational HRES model with CAMS aerosol climatology, on **Graciosa 2009-2010**



Not too bad!

Outline

Introduction

Observations and IFS

Removing first order biases

The 3D radiative effects of clouds

Conclusions

Outline

Removing first order biases

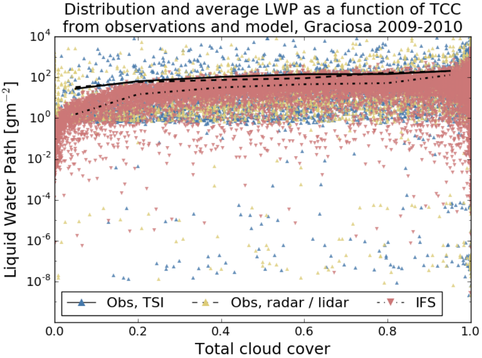
Macrophysical properties of clouds

Scattering properties of clouds

Aerosols

Low clouds in the model vs in the observations

The cloud population from the model ≠ from the observations

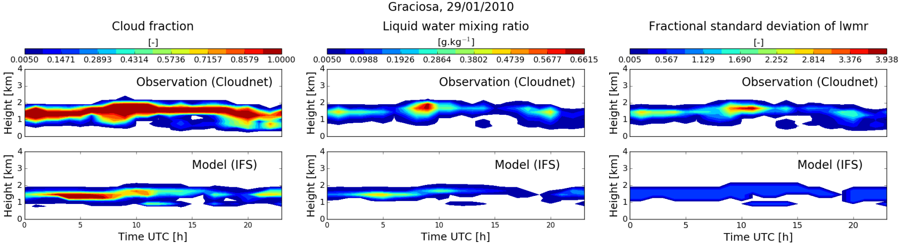


Observed clouds optically thicker than modelled clouds

Using observed clouds as input to radiation scheme

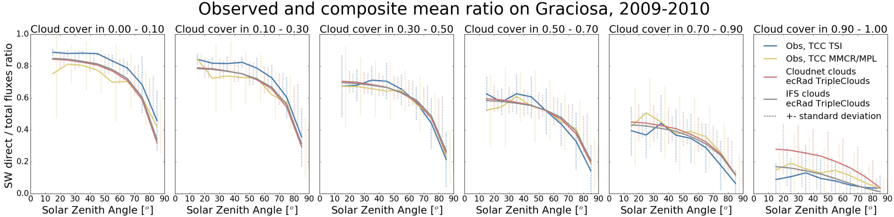
Cloudnet profiles = **retrievals interpolated to IFS grid**

- Cloud fraction
- Liquid water mixing ratio (lwmr)
- In-cloud standard deviation of lwmr



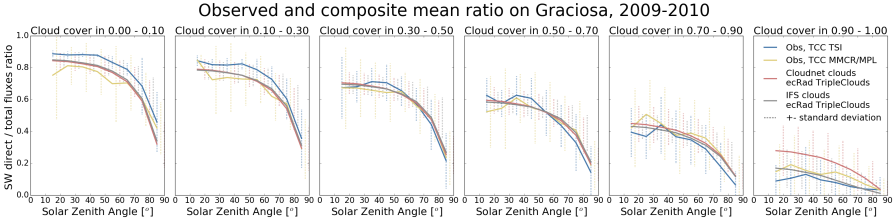
IFS radiation on observed clouds, direct to total ratio

Offline ecRad similar to operational (TripleClouds, exp-ran, FSD 0.75) on **Cloudnet profiles** extracted on **Graciosa 2009-2010**



IFS radiation on observed clouds, direct to total ratio

Offline ecRad similar to operational (TripleClouds, exp-ran, FSD 0.75) on **Cloudnet profiles** extracted on **Graciosa 2009-2010**



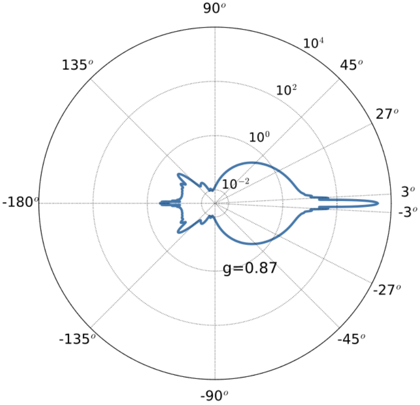
LWP small impact, more heterogeneity increases the ratio

Outline

Removing first order biases
Macrophysical properties of clouds
Scattering properties of clouds
Aerosols

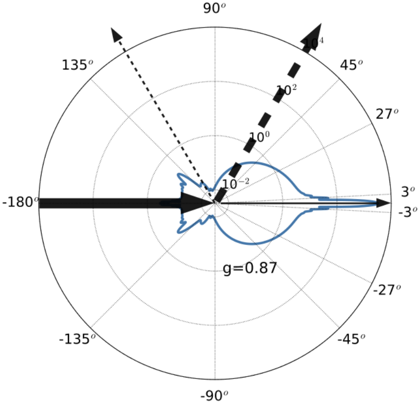
The delta Eddington scaling approximation

- Clouds scatter a lot of radiation in a **small forward solid angle**
  Logarithmic plot of Mie phase function at $\lambda = 550nm$



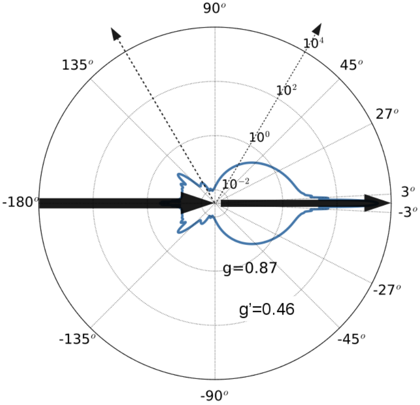
The delta Eddington scaling approximation

- Clouds scatter a lot of radiation in a **small forward solid angle**
- Not accurately represented with the 2-stream approximation



The delta Eddington scaling approximation

- Clouds scatter a lot of radiation in a **small forward solid angle**
- Not accurately represented with the 2-stream approximation
- Delta Eddington scaling : **forward scattered still 'direct'**, scaled optical properties



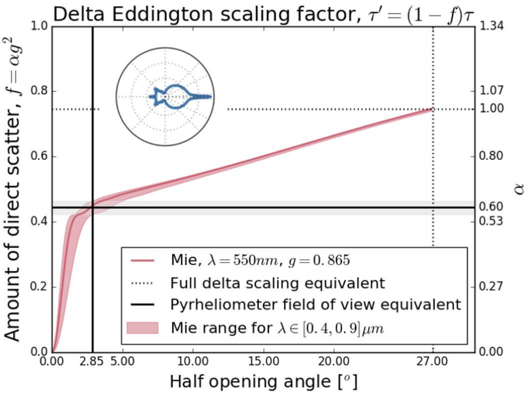
Finding the observed-equivalent scaling factor

Amount of scattered treated as direct as a function of a cutting angle θ_c

$$f = \omega \int_0^{\theta_c} \mathbb{P}_\Theta(\theta) \sin\theta \mathrm{d}\theta$$

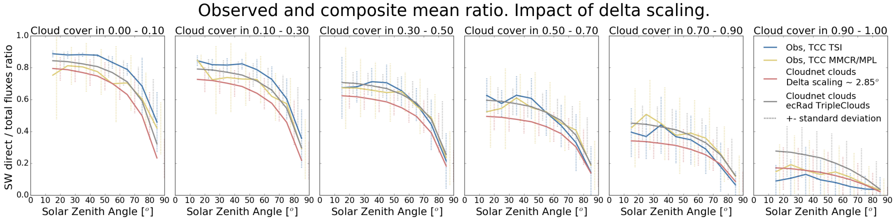
In **ecRad**, $f = g^2$
$\Rightarrow$ 'Direct' is $\theta_c \approx 27^o$

Pyrheliometer $\theta_c \approx 2.85^o$
$\Rightarrow$ scaling factor should be
$f = 0.6g^2$



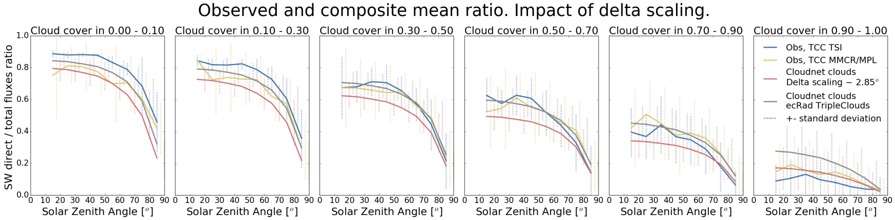
Observed-equivalent delta scaling, direct to total ratio

Offline ecRad with **modified delta scaling factor** to $\theta_c \approx 2.85^o$ on Cloudnet profiles extracted on Graciosa 2009-2010



Observed-equivalent delta scaling, direct to total ratio

Offline ecRad with **modified delta scaling factor** to $\theta_c \approx 2.85^o$ on Cloudnet profiles extracted on Graciosa 2009-2010



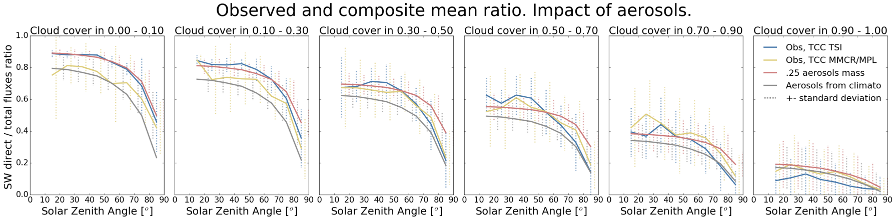
As expected the ratio decreases... making it worse in most cases!

Outline

Removing first order biases
Macrophysical properties of clouds
Scattering properties of clouds
Aerosols

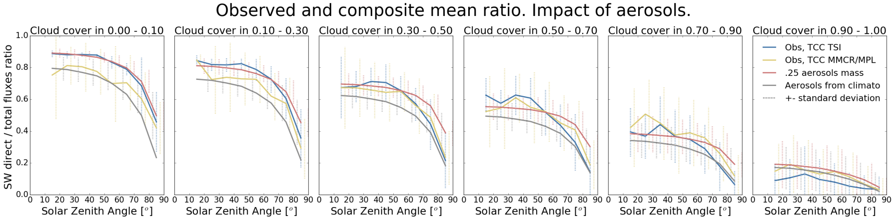
The almost clear sky bias : too much aerosols?

Offline ecRad with CAMS **aerosol mixing ratios scaled by 25%** on Cloudnet profiles extracted on Graciosa 2009-2010



The almost clear sky bias : too much aerosols?

Offline ecRad with CAMS **aerosol mixing ratios scaled by 25%** on Cloudnet profiles extracted on Graciosa 2009-2010



Scaling set to fit the ratio to TSI estimate in the ‘almost clear sky’ case

Outline

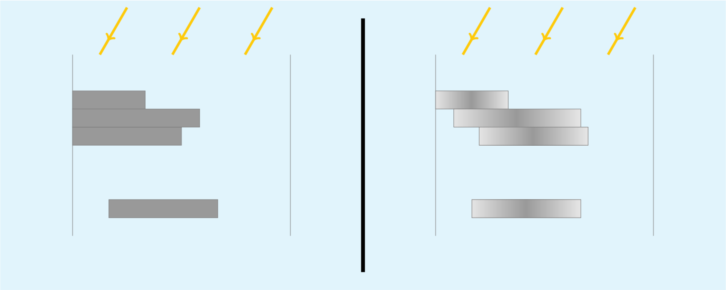
Removing any ambiguity on 3D radiative effects

The expression *3D effects* is used to describe various processes

Removing any ambiguity on 3D radiative effects

The expression *3D effects* is used to describe various processes

- **Subgrid cloud description** [McICA, TripleClouds]

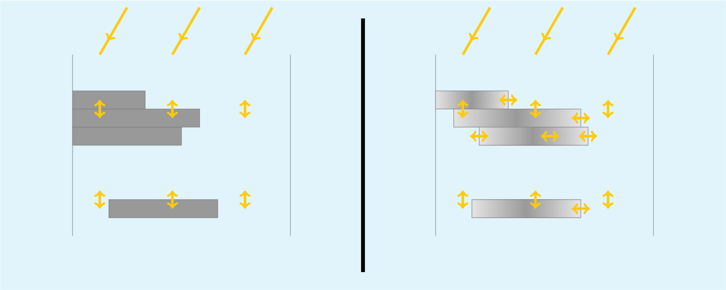


1D 3D

Removing any ambiguity on 3D radiative effects

The expression *3D effects* is used to describe various processes

- **Subgrid cloud description** [McICA, TripleClouds]
- **Subgrid horizontal transport of radiation** [SPARTACUS]

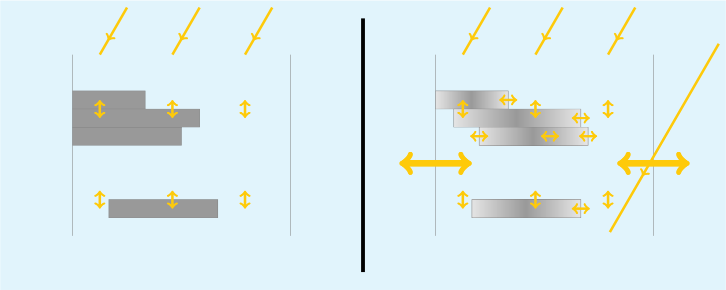


1D 3D

Removing any ambiguity on 3D radiative effects

The expression *3D effects* is used to describe various processes

- **Subgrid cloud description** [McICA, TripleClouds]
- **Subgrid horizontal transport of radiation** [SPARTACUS]
- **Intercolumnar transport of radiation** [10streams, Monte Carlo]

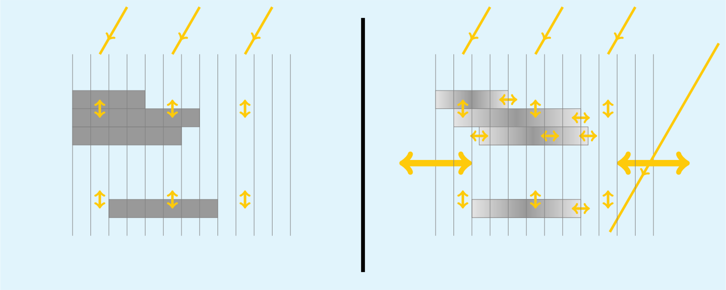


1D 3D

Removing any ambiguity on 3D radiative effects

The expression *3D effects* is used to describe various processes

- **Subgrid cloud description** [McICA, TripleClouds]
- **Subgrid horizontal transport of radiation** [SPARTACUS]
- **Intercolumnar transport of radiation** [10streams, Monte Carlo]

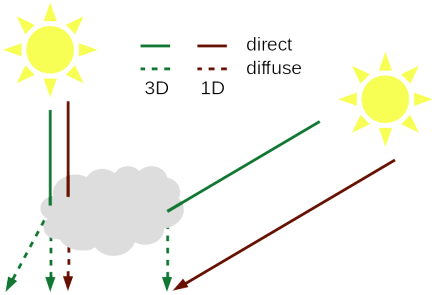


1D 3D

How would 3D effects affect the ratio?

With horizontal transport:

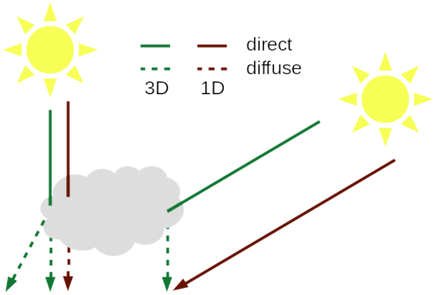
- low direct is intercepted by cloud edges ⇒ ↘ direct ⇒ ↘ ratio
- high sun is scattered through cloud edges ⇒ ↗ diffuse ⇒ ↘ ratio



How would 3D effects affect the ratio?

With horizontal transport:

- low direct is intercepted by cloud edges ⇒ ↘ direct ⇒ ↘ ratio
- high sun is scattered through cloud edges ⇒ ↗ diffuse ⇒ ↘ ratio

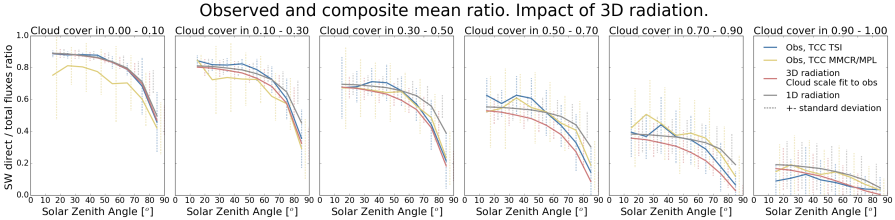


For a given cloud cover,

↘ cloud size
⇒ ↗ interface clear-cloudy
⇒ ↗ 3D effects
⇒ ↘ ratio

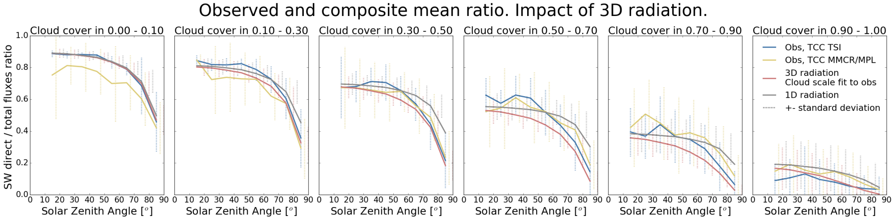
3D transport of radiation, direct to total ratio

Offline ecRad with **3D solver SPARTACUS** on Cloudnet profiles extracted on Graciosa 2009-2010



3D transport of radiation, direct to total ratio

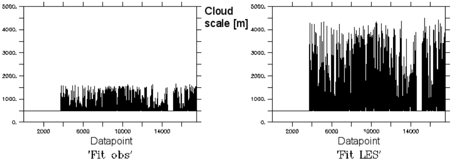
Offline ecRad with **3D solver SPARTACUS** on Cloudnet profiles extracted on Graciosa 2009-2010



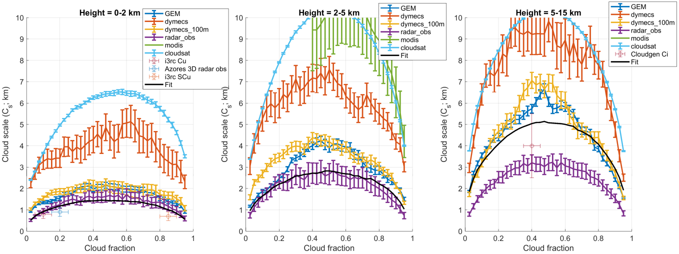
Biggest impact for broken clouds and low sun conditions

Cloud scale parametrisation, direct to total ratio

Cloud scale vertically averaged on low clouds [0-4000m]

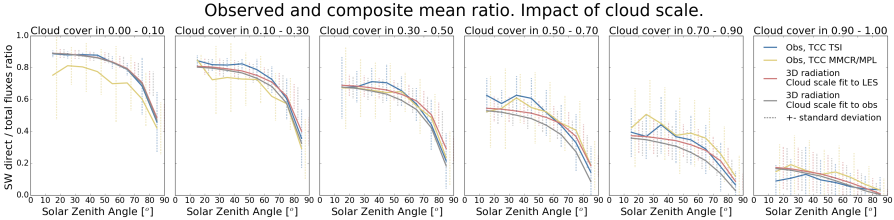


Depending on the data to which it is fitted, the parametrisation will give different typical cloud scales



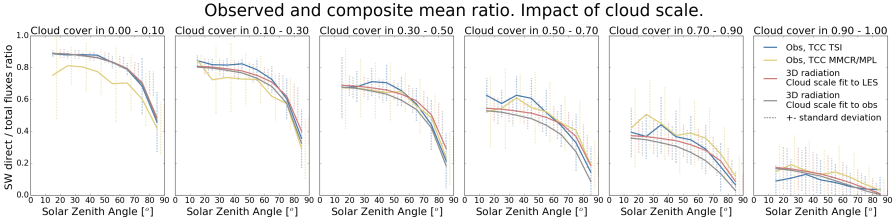
Cloud scale effect, direct to total ratio

Offline ecRad with 3D SPARTACUS, **cloud scale fitted to Dymecs**, on Cloudnet profiles extracted on Graciosa 2009-2010



Cloud scale effect, direct to total ratio

Offline ecRad with 3D SPARTACUS, **cloud scale fitted to Dymecs**, on Cloudnet profiles extracted on Graciosa 2009-2010



As expected, bigger clouds give higher ratios

Outline

Introduction

Observations and IFS

Removing first order biases

The 3D radiative effects of clouds

Conclusions

Watch out for compensating errors!

Watch out for compensating errors!

Track and eliminate first order biases

- Use all observations available: observed aerosols?
- Use consistent definition of metrics between obs and model

Watch out for compensating errors!

Track and eliminate first order biases

- Use all observations available: observed aerosols?
- Use consistent definition of metrics between obs and model

3D effects are real!

- SPARTACUS is able to represent them
- Can we use this diagnosis to evaluate the cloud scale parametrisation?

Watch out for compensating errors!

Track and eliminate first order biases

- Use all observations available: observed aerosols?
- Use consistent definition of metrics between obs and model

3D effects are real!

- SPARTACUS is able to represent them
- Can we use this diagnosis to evaluate the cloud scale parametrisation?

Extra conclusions (at least true in 2009-2010)

- Low clouds LWP underestimated in the IFS
- Aerosol mixing ratios overestimated at Graciosa


Thank you!
Photo credit: Anne Dujay

References I

Andreas, Afshin et al. *Solar Infrared Radiation Station (SIRS), Sky Radiation (SKYRAD), Ground Radiation (GNDRAD), and Broadband Radiometer Station (BRS) Instrument Handbook*. en. ARM.

Brown, A. R. et al. (2002). 'Large-eddy simulation of the diurnal cycle of shallow cumulus convection over land'. In: *Quarterly Journal of the Royal Meteorological Society* 128.582, pp. 1075–1093.

Hogan, R. J. et al. (2017). *Radiation in numerical weather prediction*. eng. ECMWF.

Hogan, Robin J and Alessio Bozzo (2018). 'A flexible and efficient radiation scheme for the ECMWF model'. en. In: *submitted to JAMES*.

Hogan, Robin J. et al. (2016). 'Representing 3-D cloud radiation effects in two-stream schemes: 2. Matrix formulation and broadband evaluation'. en. In: *Journal of Geophysical Research: Atmospheres* 121.14. ISSN: 2169-8996. DOI: 10.1002/2016JD024875. (Visited on 09/02/2017).

References II

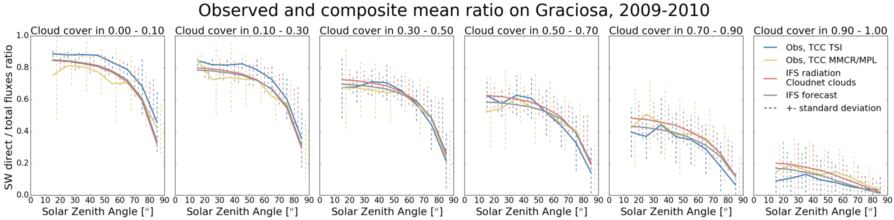
Illingworth, A. J. et al. (2007). 'Cloudnet: Continuous Evaluation of Cloud Profiles in Seven Operational Models Using Ground-Based Observations'. en. In: *Bulletin of the American Meteorological Society* 88.6, pp. 883–898. ISSN: 0003-0007, 1520-0477. DOI: 10.1175/BAMS-88-6-883. (Visited on 05/18/2018).

RADFLUX and TSISKY products (2009-2010). ARM GRW. URL: http://www.archive.arm.gov/discovery/ (visited on 05/03/2018).

Schäfer, Sophia A. K. et al. (2016). 'Representing 3-D cloud radiation effects in two-stream schemes: 1. Longwave considerations and effective cloud edge length'. en. In: *Journal of Geophysical Research: Atmospheres* 121.14. ISSN: 2169-8996. DOI: 10.1002/2016JD024876.

IFS radiation on observed clouds, direct to total ratio

Offline ecRad similar to operational (TripleClouds, exp-ran, FSD 0.75) on **Cloudnet profiles** except FSD extracted on **Graciosa 2009-2010**



IFS radiation on observed clouds, direct to total ratio

Offline ecRad similar to operational (TripleClouds, exp-ran, FSD 0.75) on **Cloudnet profiles** except FSD extracted on **Graciosa 2009-2010**