EUCLIPSE radiation intercomparison study for stratocumulus

S. Dal Gesso[*], P. Siebesma[*], R. Neggers[*], S. de Roode[†]

April 14, 2011

1 Introduction and motivation

The radiation budget of the Earth is strongly influenced by clouds with a main contribution coming from marine boundary layer clouds such as stratocumulus clouds. At the same time the representation of stratocumulus clouds in climate models is still a challenge due to the complex and subtle interaction between radiation, turbulence and condensational processes. As a result the representation of these clouds in climate models are a major source of uncertainty.

But even if climate models would represent the stratocumulus clouds correctly, it is unclear how well radiation schemes operating in these climate models are capable of retrieving the correct radiative properties for these clouds. In fact scatter plots of liquid water path (LWP) versus top of the atmosphere albedo for subtropical marine stratocumulus for a wide range of climate and numerical weather prediction models show a large spread [Siebesma et al. 2004] (see Figure 1). Since the LWP determines to first order the albedo, this large scatter suggests large differences between the various radiation schemes that are operational in these models. This observation is one of the motivations to have a more detailed intercomparison of radiation codes for stratocumulus topped boundary layers.

Another motivation is displayed in Figure 2[1] in which a strong disagreement between satellite observations ([Roebeling et al. 2006] and [Harries et al. 2005]) and a state of art radiation code such as used in the regional atmospheric climate model (RACMO) is found [Greuell et al. 2011]. It displays LWP versus albedo for stratocumulus clouds around local noon as observed off the coast west of Africa in the Southern Atlantic Ocean. The results show that:

[*]KNMI, Royal Netherlands Meteorological Institute
[†]TUD, Delft University of Technology
[1]courtesy of Wouter Greuell

- RACMO underestimates the albedo by a factor of 2 in its operational setting;
- lowering the effective radius to as low as 5.5 μm and assuming no inhomogeneity still leads to an underestimation of the albedo;
- sophisticated radiative transfer models such as the Doubling Adding KNMI (DAK) [Wang et al. 2011], gives albedo values close to observations.

If the atmospheric profiles are idealized and the same calculations are done in a Single Column Model (SCM) framework (dots in Figure 2) similar results are found. These idealized profiles form the basis for this radiation intercomparison study.

1.1 Scientific questions

The questions that we would like to answer in the present intercomparison study are:

1. How large is the spread in broadband shortwave albedo calculated by the different radiation codes for the marine stratocumulus topped boundary layer?
2. Do more sophisticated radiation codes provide albedos closer to the observations?
3. How critical are the assumptions on the internal microphysics for the radiative properties of stratocumulus clouds?
4. How sensitive are radiation codes for the used vertical resolution?

Though this intercomparison was initially motivated for radiation codes such as used in climate and numerical weather prediction models, we also cordially invite radiation codes that are used in Large Eddy Simulation (LES) models to participate, as well as more sophisticated stand alone radiation codes (such as DAK) that could serve as a reference.

The main novelty of the present intercomparison study compared to previous ones (e.g. [Oreopoulos and Mlawer 2010]) is that in the present case we specifically focus on the radiative properties of stratocumulus clouds. Addressing the questions spelled out above can be useful for checking the realism of the radiation codes that are used in operational climate models.

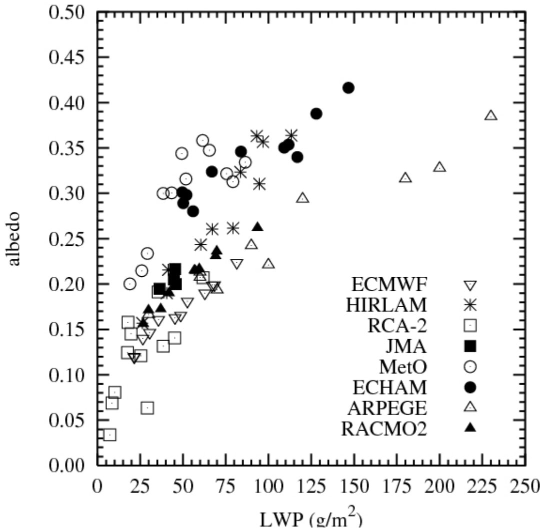

Figure 1: scatter plot of the top of the atmosphere albedo as a function of the LWP for model grid points in the North Pacific region with stratocumulus [Siebesma et al. 2004]

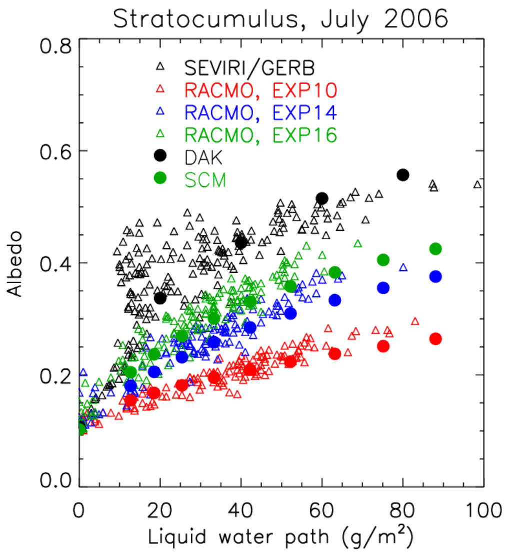

Figure 2: scatter plot of albedo at the top of the atmosphere against liquid water path: black triangles are satellite observations (albedo from GERB and liquid water path from SEVIRI), black dots are Doubling Adding KNMI (DAK) radiative transfer model results, colored triangles are RACMO results and colored dots are RACMO single column model results, more precisely operational set-up of cycle 31r1 physics experiment in red, prescribed effective radius ($r_e = 5.5 \mu m$) experiment in blue and prescribed r_e as in the previous experiment and inhomogeneity factor equal to 1 in green

2 Set-up of the simulations

The simulations start at local noon on 15 July 2006 and last just one time-step. They are located at coordinate 14.0°S and 6.5°E. For further details, see Table 1.

LAT (N)	-14.0
LON (E)	6.5
initial date	15 July 2006
initial time (UTC)	$11:30$
solar constant (W/m^2)	1325.8
cos zenith angle	0.813
albedo (-)	0.026
p_s (hPa)	1017.
SST (K)	288.4
z_0 (mm)	0.2

Table 1: general parameters.

If possible we ask for using the constant greenhouse gases concentrations provided in Table 2 (since the ozone concentration which is height dependent, it is contained in the NetCDF file).

CO_2 (ppm)	$353. \cdot 10^{-6}$
CCH_4 (ppm)	$1.72 \cdot 10^{-6}$
CNO_2 (ppm)	$310. \cdot 10^{-9}$
$CCFC_{11}$ (ppm)	$280. \cdot 10^{-12}$
$CCFC_{12}$ (ppm)	$484. \cdot 10^{-12}$

Table 2: constant greenhouse gases concentrations.

All the necessary informations are collected in the NetCDF file `radiationtest_input.nc`[2].

2.1 Initial conditions

The initial profiles are based on standard atmosphere characteristics and on observations.

- **Boundary Layer**: $0. \leq z \leq 600.$ m
  according to the adiabatic stratocumulus clouds hypothesis, the boundary layer is assumed to be well-mixed. In order to obtain different amounts of liquid water path (LWP), the liquid water equivalent potential temperature, θ_l, has been maintained constant while for the

[2]the file contains all the informations provided in ASTEX and composite cases input file and moreover cloud cover and estimated hight dependent effective radius

total water content, q_t, a value belonging to the following set has been chosen:

$$\begin{cases} \theta_l = 287.5 \quad \mathrm{K} \\ q_t = (8.00; \quad 8.50; \quad 8.57; \quad 8.64; \quad 8.71; \quad 8.78; \quad 8.85; \\ \quad 8.92; \quad 8.99; \quad 9.06; \quad 9.17; \quad 9.30; \quad 9.43; \quad 9.56; \\ \quad 9.69; \quad 9.82; \quad 9.95) \quad \mathrm{g/kg} \end{cases}$$

The first profile corresponds to the clear sky case while the others correspond to a stratocumulus clouds topped boundary layers with increasing LWP.

➤ **Free Troposphere**: $600. < z \leq 16250.$ m
the temperature, T, decreases with height, z, with a linear relation and the relative humidity, RH, is supposed to be constant.

$$\begin{cases} T = (-6.55946\mathrm{K/km}) \cdot z + (302.455\mathrm{K}) \\ RH = 0.15 \end{cases}$$

➤ **Tropopause**: $16250. < z \leq 24700.$ m
the temperature, T, increases with height, z, with a linear relation and the total water content, q_t, is supposed to be null.

$$\begin{cases} T = (3.40457\mathrm{K/km}) \cdot z + (138.474\mathrm{K}) \\ q_t = 0.\mathrm{g/kg} \end{cases}$$

➤ **Stratosphere**:
The stratosphere is composed by two parts, in both q_t is null but temperature profiles are as follows:

- $24700. < z \leq 30650.$ m: the temperature remains constant and equal to the value that it reaches at the tropopause top:
  $T = 222.5$ K;
- $z > 30650.$ m: the temperature starts to decrease linearly again:
  $T = (-1.\mathrm{K/km}) \cdot z + (253.32\mathrm{K})$.

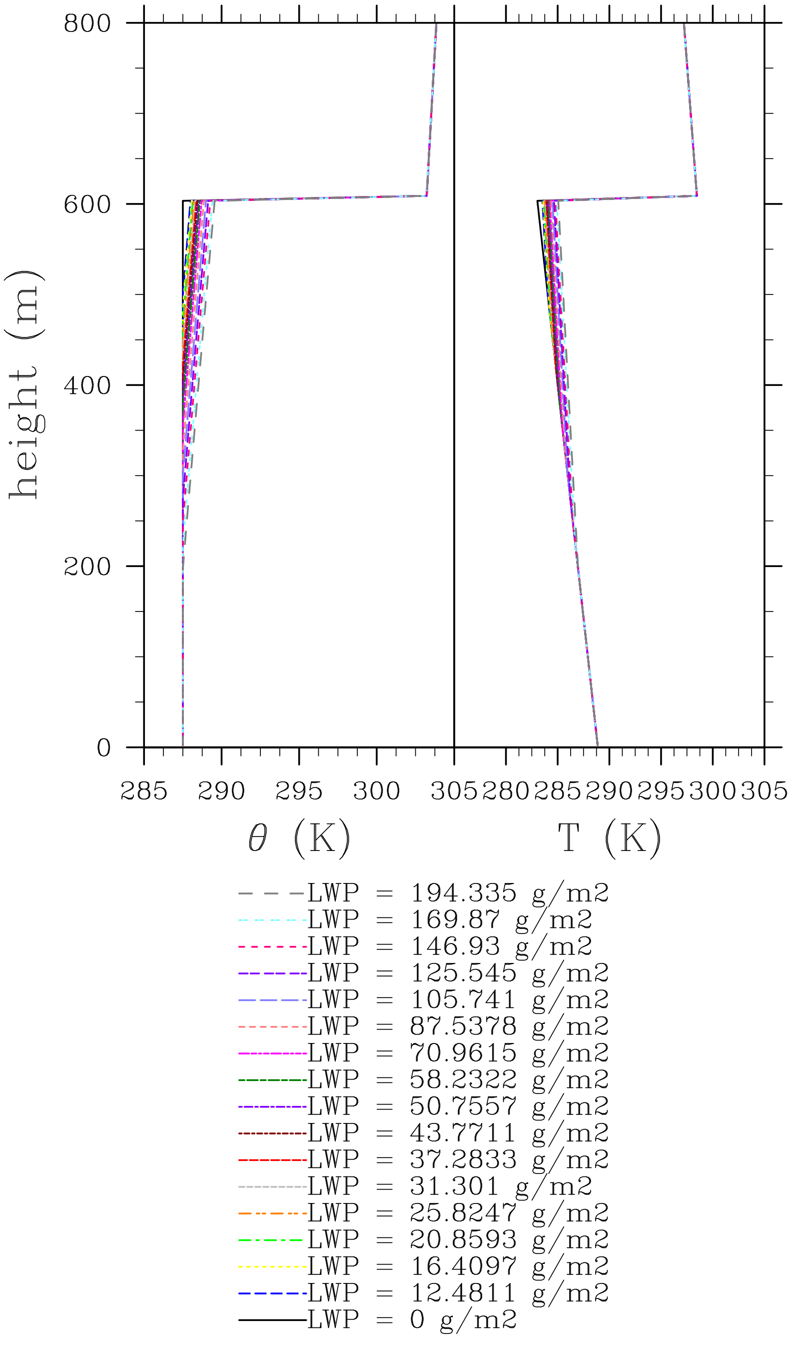

Figure 3: profiles of potential temperature (on the left) and temperature (on the right) in the boundary layer.

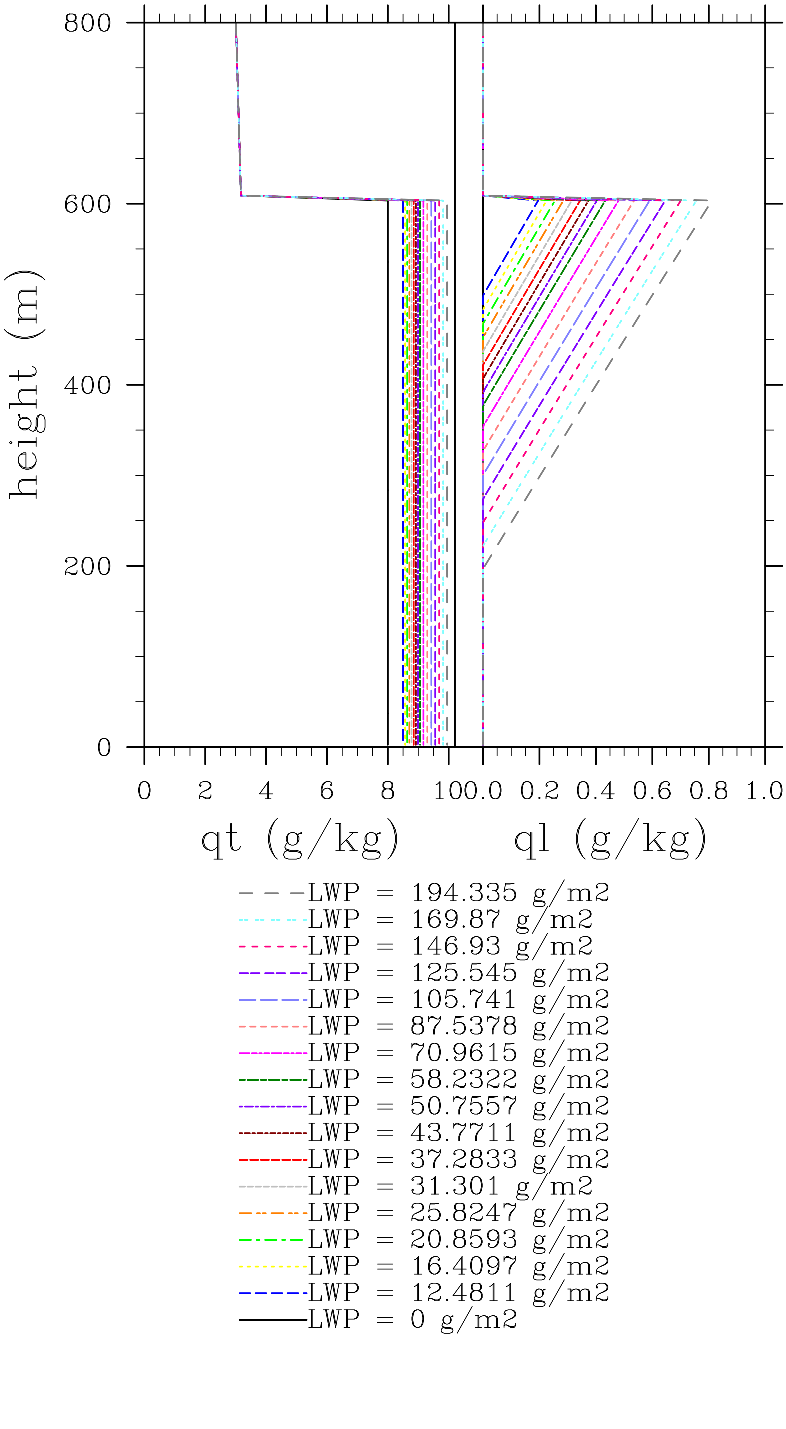

Figure 4: profiles of total water content (on the left) and liquid water content (on the right) in the boundary layer.

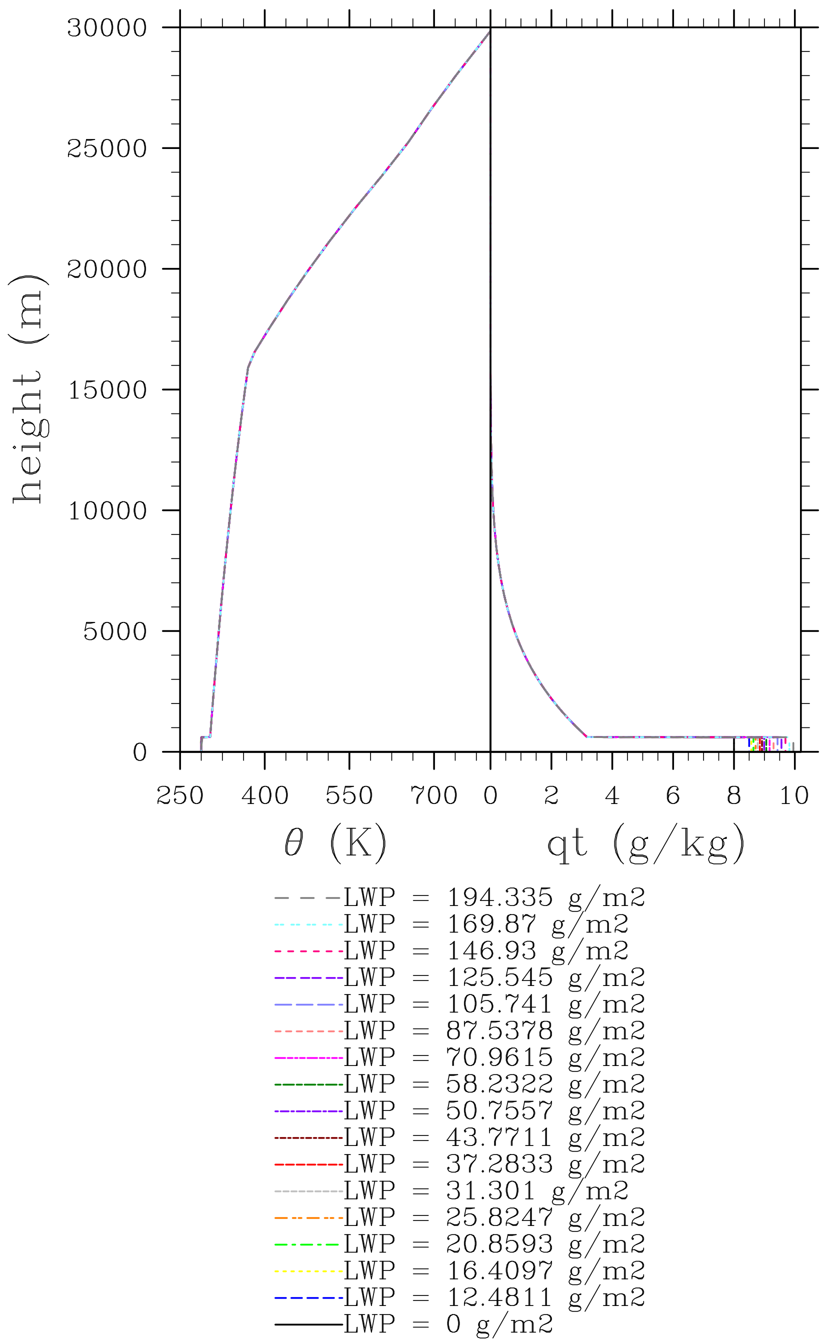

Figure 5: profiles of potential temperature (on the left) and total water content (on the right) up to the top of the atmosphere.

2.2 Microphysics

In order to study the various impacts of the cloud microphysical assumptions we ask for three different sets of simulations.

As a first experiment (SET A) we ask for results obtained by simply using the default operational setup of the model as they are used in the CMIP5 climate model runs. This is useful to assess how the various radiation codes will respond to stratocumulus fields in their operational setting, in which they often assume a simple climatology for their effective radius and sometimes assume a fixed inhomogeneity factor to take spatial inhomogeneity of the LWP into account.

In the second experiment (SET B) we ask to constrain the cloud microphysics through assuming no spatial inhomogeneity in the liquid water content. So models that are employing an inhomgeneity factor are asked to set this to 1. Furthermore we assume no dispersion in the cloud droplet distribution (*i.e.* all the droplets have the same prescribed radius at a given height). A further common (but not so realistic) hypothesis in climate and NWP models is that the effective radius is constant with height in stratocumulus. We therefore require a constant effective radius with height which is set equal to 9. μm, according to SEVIRI observations. This implies that the cloud droplet number concentration, N_c, varies with height as follows:

$$N_c(z) = \left(\frac{4}{3}\pi\rho_l\right)^{-1} {r_e}^{-3}\rho_a q_l(z)$$

where ρ_a is the air density, ρ_l the liquid water density and q_l the liquid water content. With these assumptions the optical depth τ, reads as

$$\tau = \frac{3}{2}\frac{1}{\rho_l r_e}\int_0^{+\infty}\rho_a q_l(z)dz$$

Finally, as a more realistic variation on the second experiment, we require in the third experiment (SET C) a constant cloud droplet number concentration: $N_c = 200.\text{cm}^{-3}$. Along with the previous assumptions of non-dispersive delta-peaked distribution of the cloud droplet size distribution and no inhomogeneity for the liquid water content, this leads to an effective radius which is height dependent

$$r_e(z) = \left(\frac{4}{3}\pi\rho_l N_c\right)^{-1/3}(\rho_a q_l(z))^{1/3}$$

and an optical depth given by

$$\tau = \left(\frac{9}{2}\pi N_c \rho_l^{-2}\right)^{1/3}\int_0^{+\infty}(\rho_a q_l(z))^{2/3}dz$$

The description of the intercomparison study sets can thus be summarized as:

- SET A: operational set-up;
- SET B: prescribed effective radius: $r_e = 9\mu m$;
- SET C: constant cloud droplet number concentration: $N_c = 200.\text{cm}^{-3}$.

2.3 Vertical resolution

Since vertical resolution might influence the results substantially we require that radiation codes run as Single Column Model versions of climate and numerical weather prediction models provide results at two different resolutions:

1. the standard resolution such as used in the operational runs;
2. a higher prescribed resolution.

The higher prescribed resolution is defined by the hybrid coordinate constants A's and B's, that determine the pressure at the model half levels through:

$$p_{k+1/2} = A_{k+1/2} + B_{k+1/2} \cdot p_s$$

where p_s is the prescribed surface pressure. The A's and B's are provided in the NetCDF file `radiationtest_input.nc`.

Radiation codes that run in LES models should run at a vertical resolution of 10 m in the lowest 1 kilometer. Beyond this height the resolution can be made coarser through the use of a stretched grid.

3 Requested output

We ask for three NetCDF files for scalar quantities called "lastname_rad_scal_set.nc" (*e.g.*: the file containing results for SET A is called `myname_rad_A.nc`) including:

- {LWP} Liquid Water Path (g/m^2)
- {tau} optical depth (-)
- {albedo} albedo at the ToA (-)
- {CC} Cloud Cover (-)

and three NetCDF files called "lastname_rad_prof_set.nc" including:

- {pres} pressure levels (Pa)

- {height} height levels (m)
- {T} temperature (K)
- {qv} water vapour content (kg/kg)
- {ql} liquid vapour content (kg/kg)
- {CF} Cloud Fraction (-)
- {SW_up} upward shortwave radiation (W/m^2)
- {SW_dn} downward shortwave radiation (W/m^2)
- {LW_up} upward longwave radiation (W/m^2)
- {LW_dn} downward longwave radiation (W/m^2)

for each simulations set.
The results obtained by using the high resolution grid should be named: "lastname_rad_scal_set_hr.nc" or "lastname_rad_prof_set_hr.nc".

Please provide in each NetCDF file any useful information as a global attribute.

References

[Greuell et al. 2011] Greuell, W., E. van Meijgaard, N. Clerbaux and J. F. Meirink, accepted, *Evaluation of model predicted top-of-atmosphere radiation and cloud parameters over Africa with observations from GERB and SEVIRI*, J. Climate.

[Siebesma et al. 2004] Siebesma A.P., C. Jakob, G. Lenderink, R.A.J. Neggers, E. van Meijgaard, J. Teixeira, J. Calvo, A. Chlond, H. Grenier, C. Jones, M. Kohler, H. Kitagawa, P. Marquet, F. Muller, D. Olameda and C. Severijns, 2004, *Cloud representation in General Circulation Models over the Northern Pacific Ocean: A EUROCS intercomparison study*, Quart. J. Roy. Meteor. Soc., 130 3245-3268.

[Oreopoulos and Mlawer 2010] Oreopoulos, L. and E. Mlawer, 2010, *The continual intercomparison of radiation codes (CIRC)*, Bull. Am. Met. Soc., 91, 305-310, doi: 10.1175/2009BAMS2732.1.

[Harries et al. 2005] Harries, J.E., J.E. Russell, J.A. Hanafin, H. Brindley, J. Futyan, J. Rufus, S. Kellock, G. Matthews, R. Wrigley, A. Last et al., 2005, *The Geostationary Earth Radiation Budget project*, Bull. Amer. Meteor. Soc., 86, 945-960.

[Roebeling et al. 2006] Roebeling, R. A., A. J. Feijt and P. Stammes, 2006, *Cloud property retrievals for climate monitoring: Implications of differences between Spinning Enhanced Visible and Infrared Imager (SEVIRI) on Meteosat-8 and Advanced Very High Resolution Radiometer (AVHRR) on NOAA-17*, J. Geophys. Res., 111, D20210, doi: 10.1029/2005JD006990.

[Wang et al. 2011] Wang, P., W. H. Knap, and P. Stammes, 2011, *Cloudy-sky shortwave radiative closure for a Baseline Surface Radiation Network site*, J. Geophys. Res., doi:10.1029/2010JD015141, in press