Tuning of direct albedo in ACRANEB2 scheme

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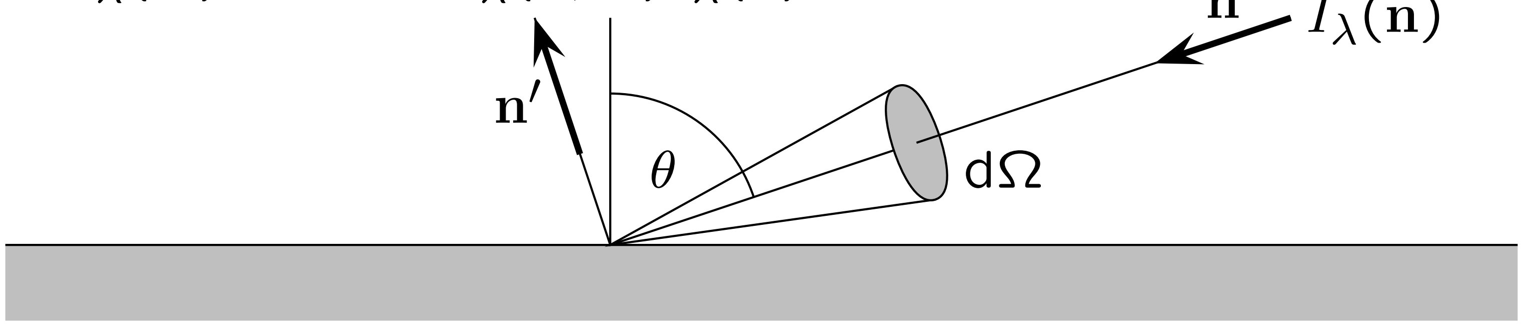
Introduction

- at school we learned that "sun heats the earth's surface which in turn heats the atmosphere"
- in order to get correct shortwave surface energy budget, both surface insolation and albedo must be modeled properly
- in original ACRANEB scheme parameterization of direct surface albedo was too crude, it was therefore revised with introduction of ACRANEB2
- all what follows applies to ISBA case only, albedo computed inside SURFEX scheme can be very different

From spectral BRDF to broadband albedo

- in general case, reflecting surface is described by wavelength dependent **bidirectional reflectance distribution function** (BRDF):

$$\mathrm{d}I_\lambda(\mathbf{n}') = \mathrm{BRDF}_\lambda(\mathbf{n},\mathbf{n}')I_\lambda(\mathbf{n})\cos\theta\,\mathrm{d}\Omega$$



I_λ – spectral radiance of incoming ($\mathbf{n}$) or reflected ($\mathbf{n}'$) radiation
θ – incident angle of incoming radiation
$\mathrm{d}\Omega$ – solid angle element for incoming radiation

- when such detailed description is unavailable or not necessary, spectral and angular integrations can be performed to introduce **broadband albedo**

- it provides simplified description where details like angular distribution of reflected radiation or effects of surface anisotropy are lost

Definition of broadband albedos

- broadband albedo is usually defined as the ratio of reflected to incoming solar flux across horizontal surface

- this ratio is dependent on angular distribution of incoming radiation

- important are two limit cases:

  1. incoming radiation is fully collimated $\Rightarrow$ **black sky** or **direct** albedo α_{dir}, depending on sun elevation
  2. incoming radiation is isotropic $\Rightarrow$ **white sky** or **diffuse** albedo α_{dif}

- when incoming solar flux contains both direct and diffuse components, outgoing flux is given by **blue sky** albedo α (where D is proportion of diffuse component):

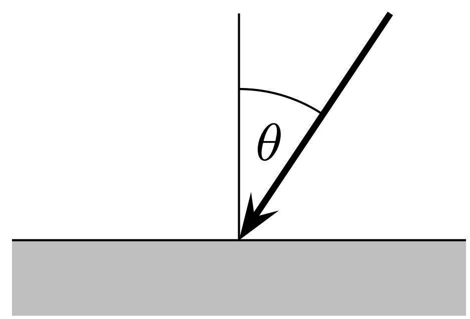
$$\alpha = D\alpha_{\text{dif}} + (1 - D)\alpha_{\text{dir}}$$

- it is assumed that reflected radiation is diffuse and isotropic

Relation between direct and diffuse albedos

- direct and diffuse albedos are not independent, but related by integral constraint (where μ is cosine of solar zenithal angle θ):

$$\alpha_{\mathsf{dif}} = 2\int_0^1 \alpha_{\mathsf{dir}}(\mu)\mu \, \mathrm{d}\mu \qquad \mu = \cos\theta$$



- above expression assumes diffuse albedo defined for isotropic incoming radiation

- however, not all albedo parameterizations respect relation between α_{dir} and α_{dif}

Geleyn's formula (1)

- Geleyn's formula proposes **heuristic** dependency of direct albedo on sun elevation measured by cosine of solar zenithal angle μ:

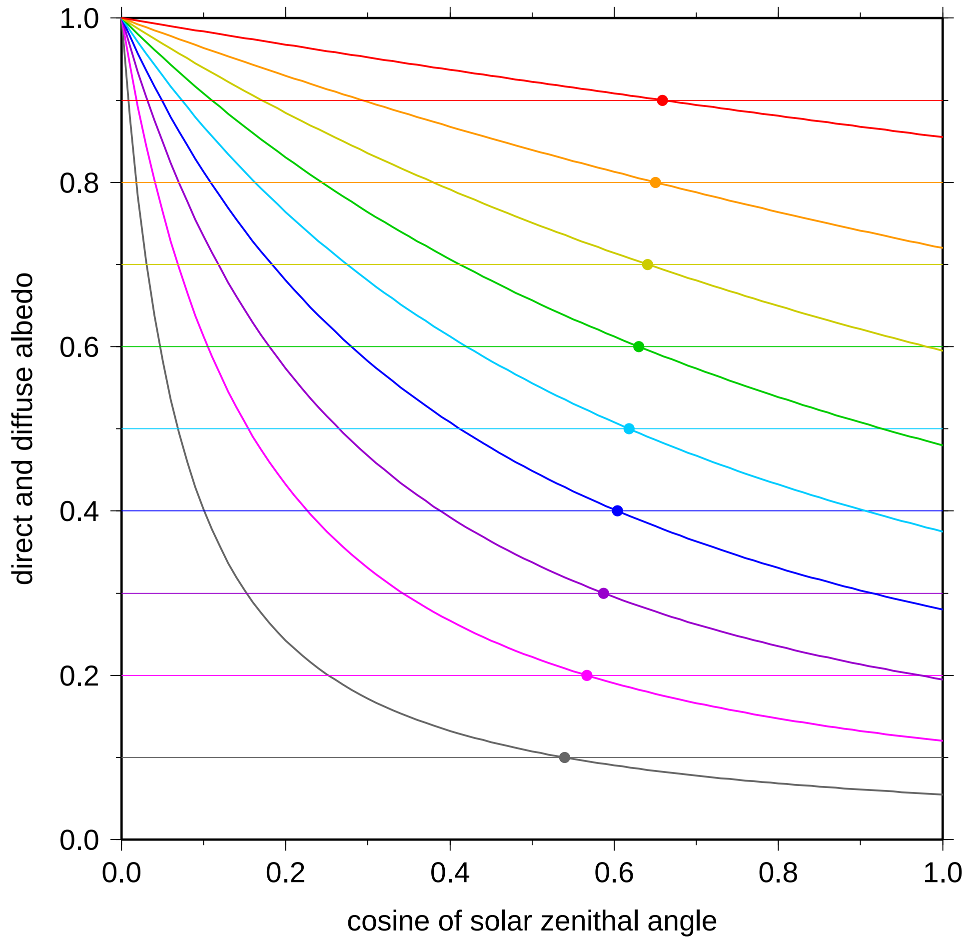
$$\alpha_{\mathrm{dir}}(\mu) = \frac{1 + \frac{\mu}{2}\left(\frac{1}{\alpha_{\mathrm{dif}}} - 1\right)}{\left[1 + \mu\left(\frac{1}{\alpha_{\mathrm{dif}}} - 1\right)\right]^2}$$

$$\lim_{\mu \to 0} \alpha_{\mathrm{dir}}(\mu) = 1 \qquad \lim_{\mu \to 1} \alpha_{\mathrm{dir}}(\mu) = \frac{1}{2}\alpha_{\mathrm{dif}}(\alpha_{\mathrm{dif}} + 1)$$

- by construction, it preserves integral constraint between direct and diffuse albedos and ensures $\alpha_{\mathrm{dir}} \in [0, 1]$ for all permissible μ and α_{dif}

- for small diffuse albedo Geleyn's formula qualitatively describes undisturbed water surface, with total reflection for sun on the horizon and strong absorption for sun at zenith

Geleyn's formula (2)



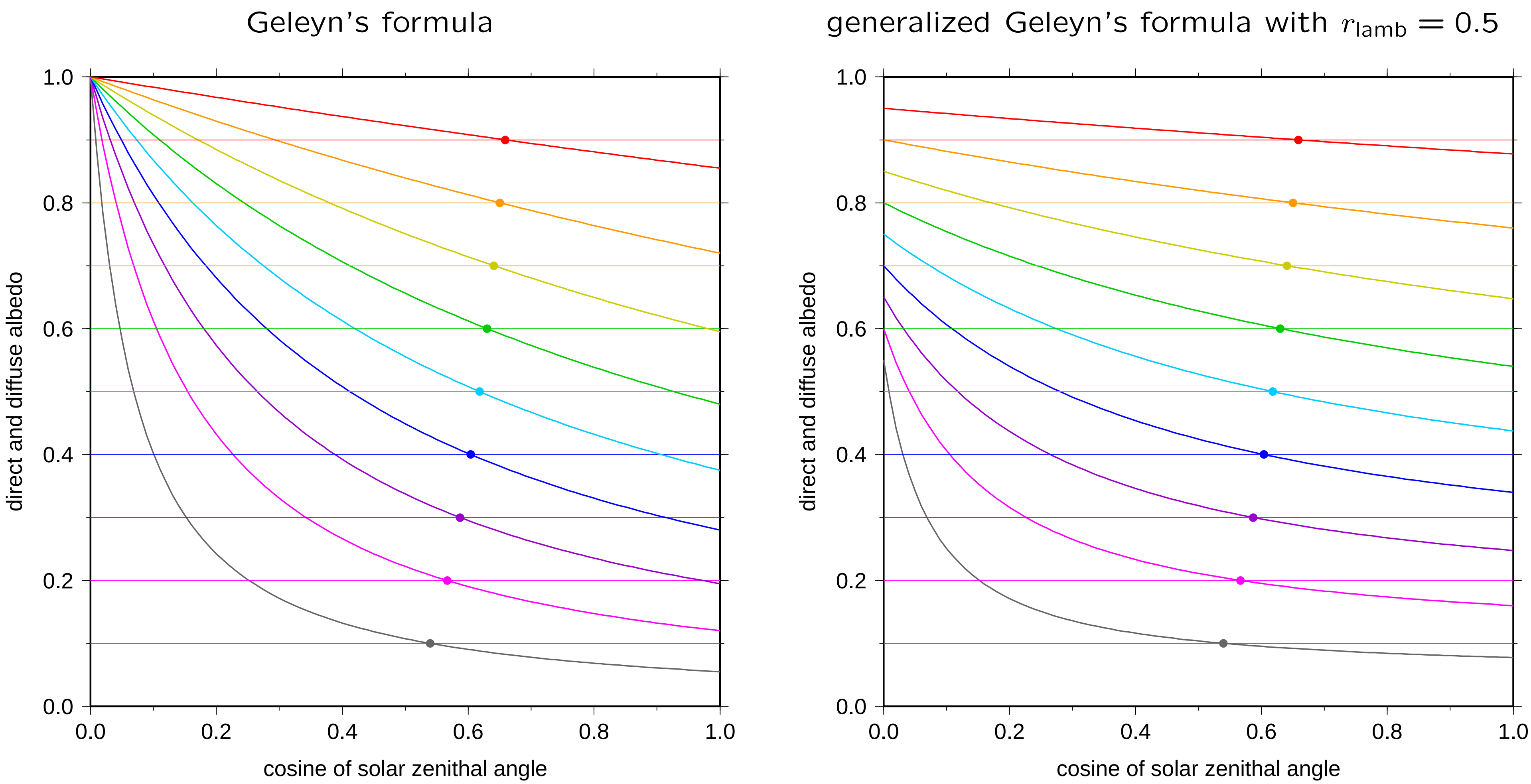
Generalized Geleyn's formula (1)

- in original ACRANEB scheme, Geleyn's formula was used for each type of surface
- this was not optimal, since for land and snow dependency of direct albedo on sun elevation is weaker than for water surface
- for this reason, Geleyn's formula was generalized by adding proportion of Lambertian reflection r_{lamb}:

$$\alpha'_{\text{dir}}(\mu) = (1 - r_{\text{lamb}})\alpha_{\text{dir}}(\mu) + r_{\text{lamb}}\alpha_{\text{dif}}$$

- integral constraint between direct and diffuse albedos remains preserved
- positive r_{lamb} decreases variaton of direct albedo with sun elevation
- two extreme cases are $r_{\text{lamb}} = 0$ (Geleyn's formula for water like surface) and $r_{\text{lamb}} = 1$ (Lambertian surface with direct albedo independent on sun elevation)

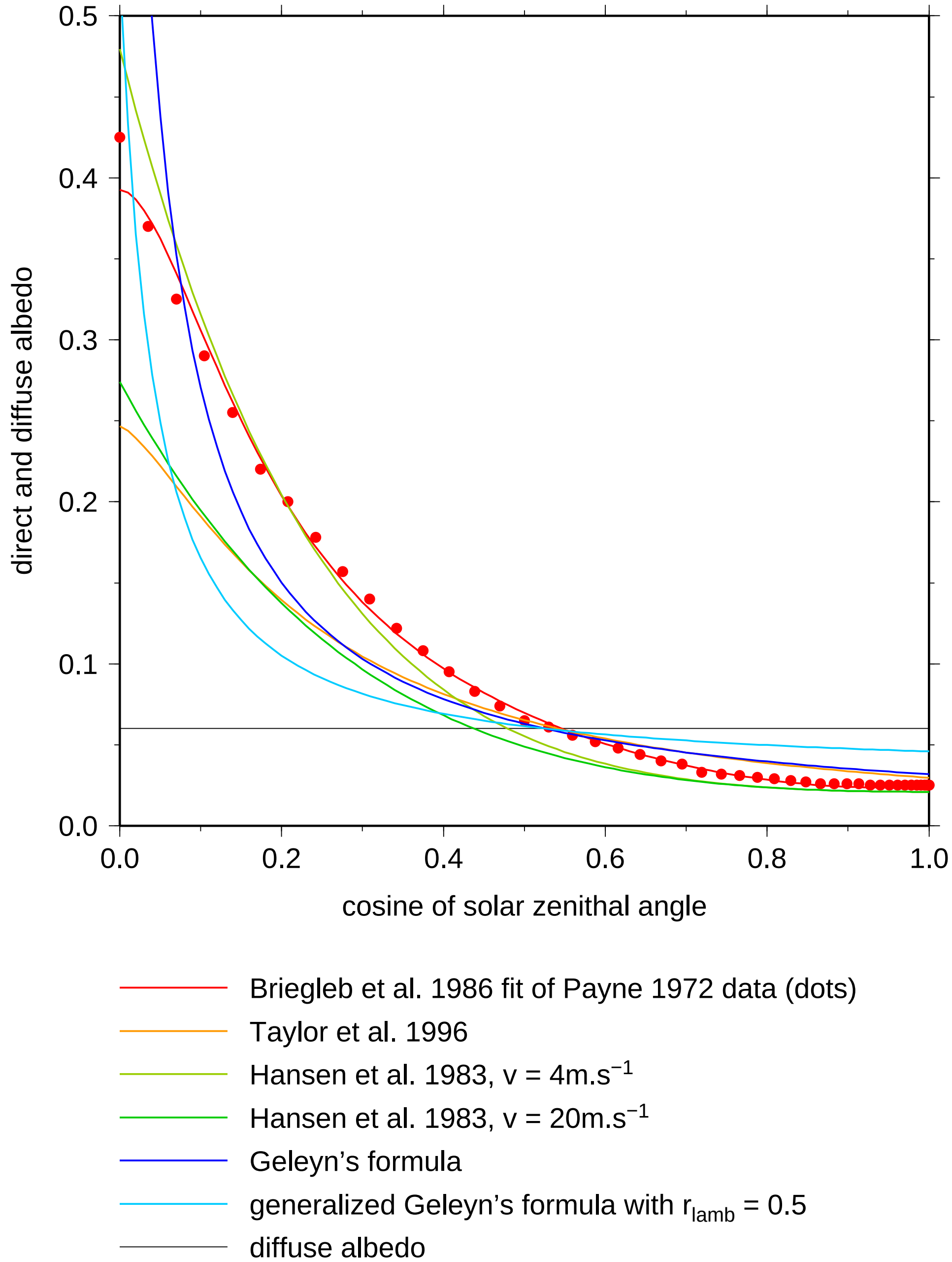
Generalized Geleyn's formula (2)



How to tune proportion of Lambertian reflection?

- first it is necessary to find reliable reference for each type of surface
- following papers were used in this study:
  1. Payne 1972 / Briegleb et al. 1986, Taylor et al. 1996 and Hansen et al. 1983 for **sea** albedo
  2. Yang et al. 2008 for **snow-free land** albedo
  3. Gardner and Sharp 2010 for **snow** albedo
- for each surface, proportion of Lambertian reflection giving best match of generalized Geleyn's formula with reference was sought

Direct albedo of sea (1)



Direct albedo of sea (2)

- various references for direct sea albedo differ considerably
- one reason can be presence of waves, which have strong influence at low sun elevations
- comparison with Hansen et al. 1983 parameterization which accounts for wind speed confirms that Payne 1972 data were measured at low wind speeds, while Taylor et al. 1996 parameterization was developed for high wind speeds
- still, there is quite big spread for high sun elevations unrelated to waves
- for most references diffuse sea albedo computed by angular integration is close to 0.06, but for Hansen et al. 1983 it is significantly less when the wind speed is high

Direct albedo of sea (3)

- for higher sun elevations, Geleyn's formula with diffuse albedo 0.06 is very close to Taylor et al. 1996 results, while for low sun elevations it crosses measurements of Payne 1972

- it thus roughly corresponds to undisturbed water surface

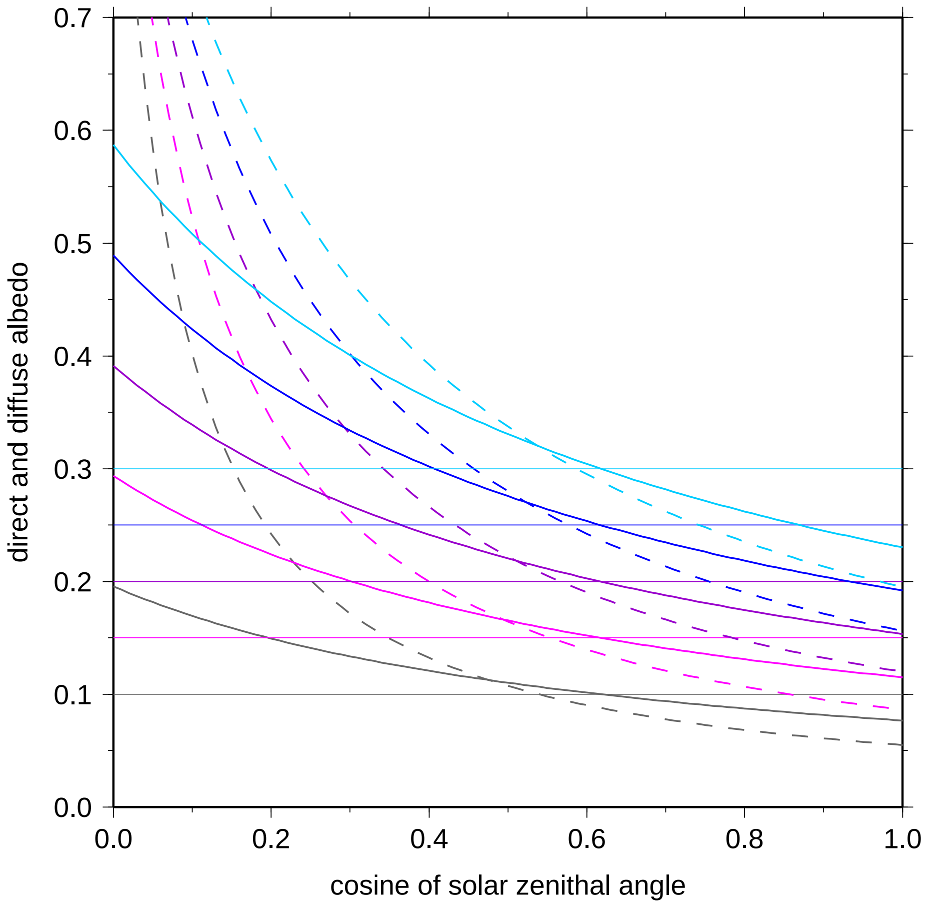
- adding proportion of Lambertian reflection for sea is not profitable, since it distorts Geleyn's formula in undesired way

- departure of unmodified Geleyn's formula from other parameterizations is not a big problem, because the largest deviation happens at insignificant low sun elevations

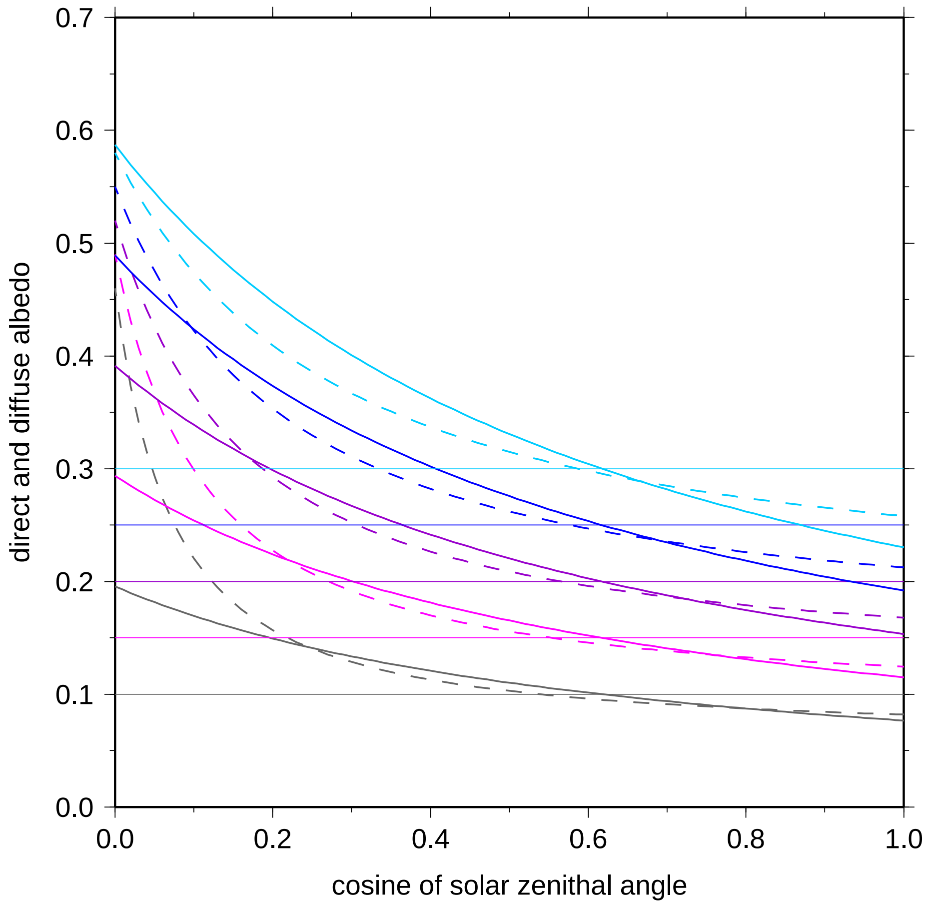
- moreover, in short range numerical weather prediction sea surface temperature is prescribed, so the surface energy budget is not in question

Direct albedo of snow-free land (1)

Geleyn's formula



generalized Geleyn's formula with $r_{\mathrm{lamb}} = 0.6$



thick solid lines – Yang et al. 2008; thick dashed lines – (generalized) Geleyn's formula

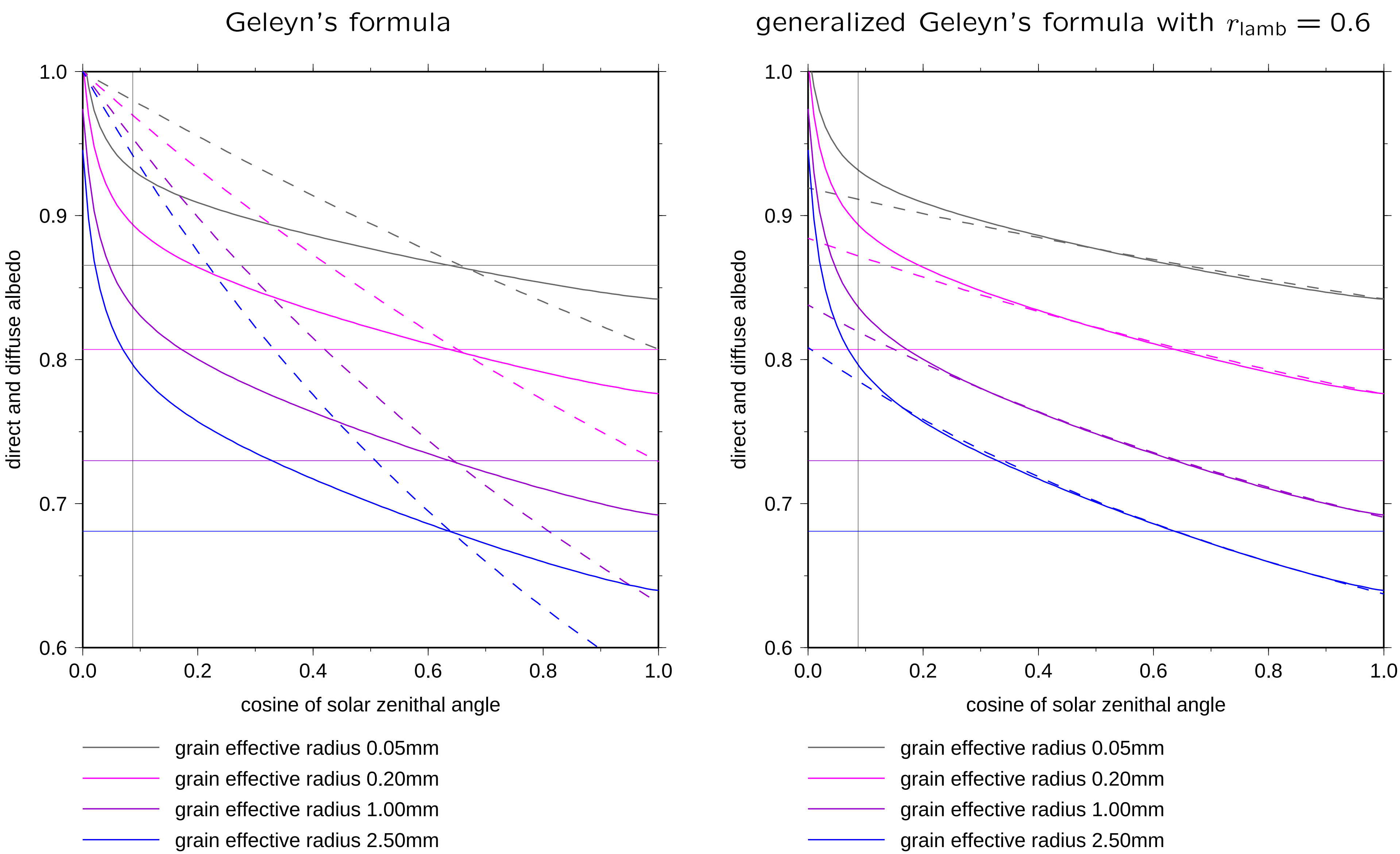
Direct albedo of snow-free land (2)

- for diffuse albedo ranging from 0.1 to 0.3, best match between generalized Geleyn's formula and Yang et al. 2008 reference is obtained for $r_{\mathrm{lamb}} \sim 0.6$

- match is far from perfect especially for weakly reflecting surfaces at low sun elevations

- this is not assumed as serious problem since for low sun elevations both reference data are uncertain and incoming solar flux crossing horizontal surface is weak

Direct albedo of snow (1)



thick solid lines – Gardner and Sharp 2010; thick dashed lines – (generalized) Geleyn's formula

Direct albedo of snow (2)

- for diffuse albedo ranging from 0.68 to 0.87, best match between generalized Geleyn's formula and reference retrieved from Gardner and Sharp 2010 is obtained again for $r_{\text{lamb}} \sim 0.6$

- this time the match is nearly perfect, the only exception being low sun elevations

- this is not much important for the same reasons as in the case of snow-free land

- for example, data of Gardner and Sharp 2010 were given only for sun elevations greater or equal to 5°, so the region to the left from thin vertical line is extrapolated

Implementation in ACRANEB/ACRANEB2

- because of similar tuning for land and snow, it was decided to introduce only two values of r_{lamb} – one for open water, another for solid surfaces (land, snow, ice)

- in model code they are set via `&NAMPHY3` namelist variables:

  `RLAMB_WATER` – proportion r_{lamb} for open water
  `RLAMB_SOLID` – proportion r_{lamb} for land, snow, ice

- default values are zero in order to have backward compatibility, but in ACRANEB2 baseline version it is recommended to use:

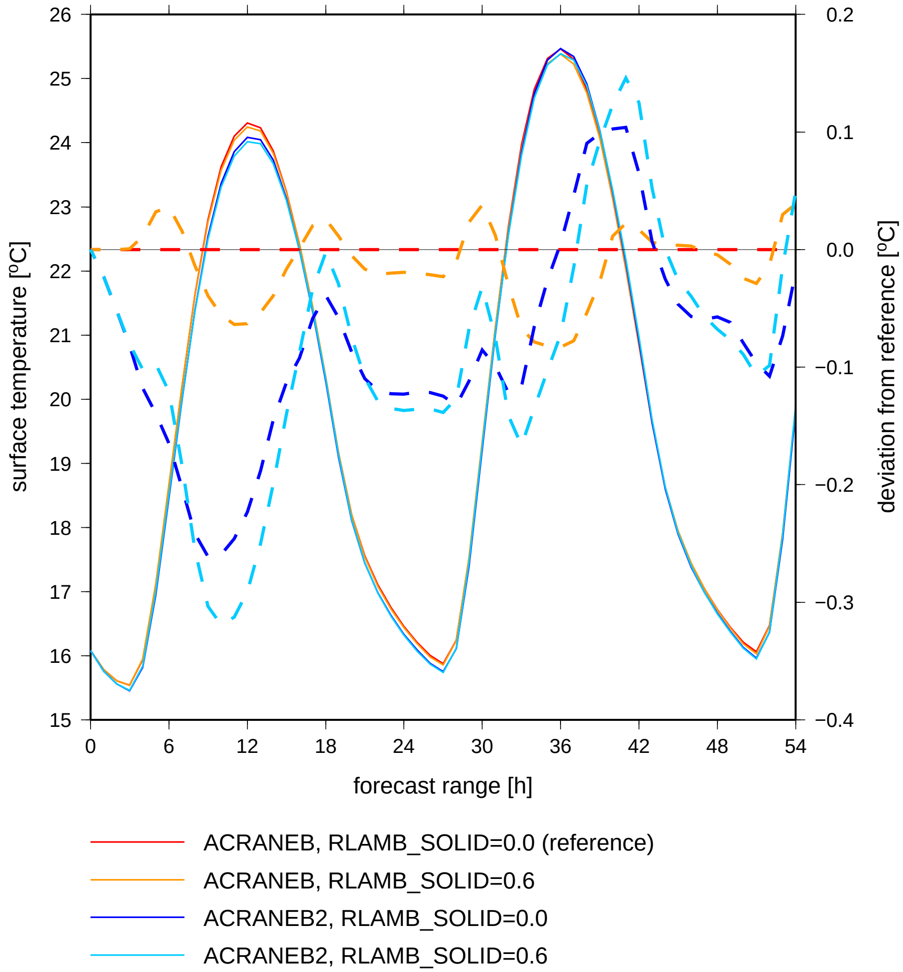
  ```
  RLAMB_WATER=0.0
  RLAMB_SOLID=0.6
  ```

- in ISBA scheme there is no tiling (all gridbox is occupied either by sea or by land), so within each gridbox only single value of r_{lamb} is applied, selected according to land-sea mask

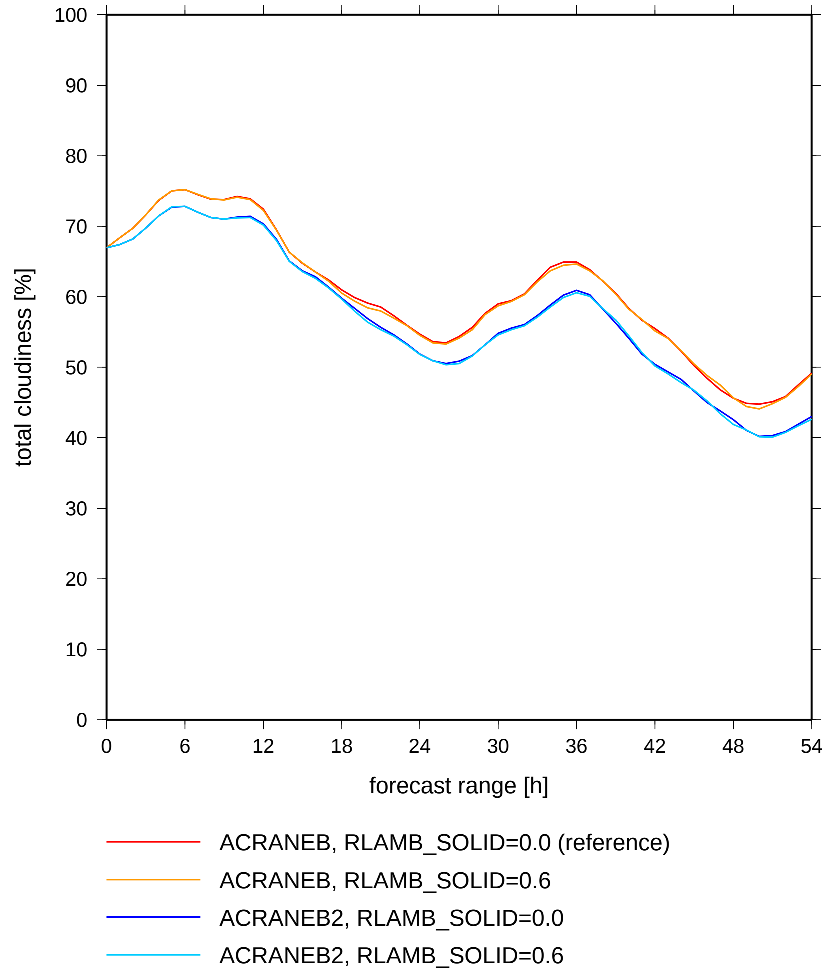
Impact of retuned direct albedo in mid-latitude summer convective case (1)

ALADIN/CHMI integration starting on 29-Jun-2009 00 UTC,
evolution of spatial average on domain 22.5° × 12.5°

surface temperature / deviation from reference



total cloudiness



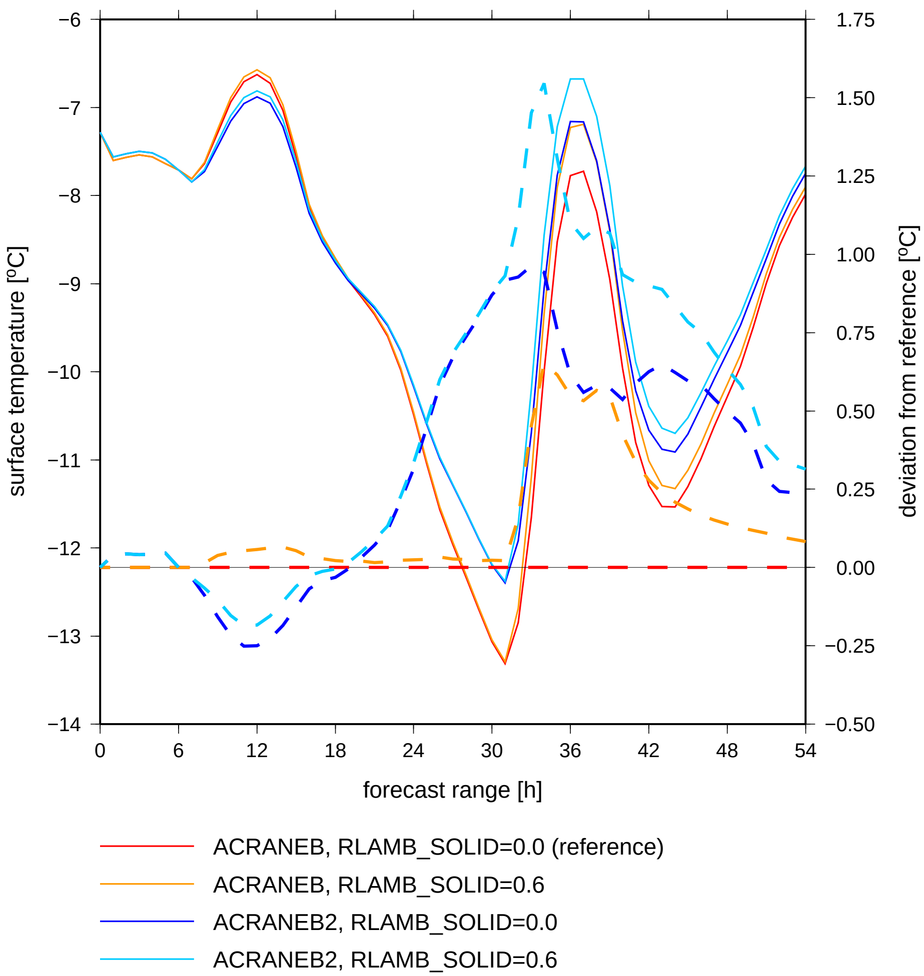
Impact of retuned direct albedo in mid-latitude summer convective case (2)

- averaging domain covering Central Europe was used, having suitable conditions for convection
- in the morning and in the evening, land surface becomes warmer due to less reflection (reduced direct albedo) for low sun elevations
- around noon, land surface becomes colder due to more reflection (increased direct albedo) for high sun elevations
- change in surface temperature coming from retuned direct albedo is several times weaker than the change coming from ACRANEB to ACRANEB2 switch (maximum departure on the first day 0.06 K versus 0.26 K)

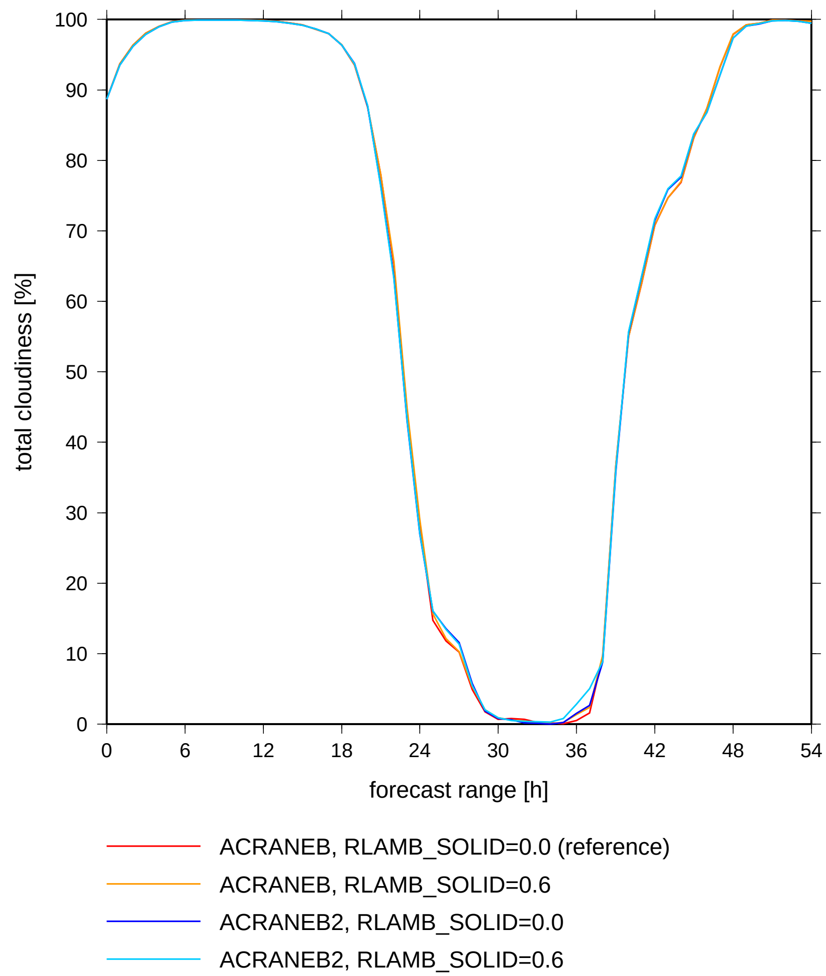
Impact of retuned direct albedo in mid-latitude winter case (1)

ALADIN/CHMI integration starting on 26-Jan-2010 00 UTC,
evolution of spatial average on domain $1^\circ \times 1^\circ$

surface temperature / deviation from reference



total cloudiness



Impact of retuned direct albedo in mid-latitude winter case (2)

- small averaging domain covered with snow was selected, such that first day is overcast and second day is clear
- due to reduced direct snow albedo for low sun elevations, surface becomes warmer during the day
- impact during first day (overcast) is weak, since almost all incoming solar flux is diffuse
- impact during second day (clear) is much stronger, since incoming solar flux is dominated by direct component
- change in surface temperature coming from retuned direct albedo is somewhat weaker than the change coming from ACRANEB to ACRANEB2 switch (maximum departure on the second day 0.6 K versus 1.0 K)

Summary and conclusions (1)

- following Yang et al. 2008 conclusions, we assume that the most important dependency of direct surface albedo is on sun elevation

- other influences like soil moisture and type, vegetation, snow age or change of spectral composition of incoming solar radiation due to clouds can enter via modification of diffuse albedo

- generalized Geleyn's formula with proportion of Lambertian reflection $r_{\mathrm{lamb}} = 0.6$ gives much better match of direct albedo with reference results for both land and snow

- for open water it is best to keep $r_{\mathrm{lamb}} = 0$, still there is space for improvement by including effect of waves, important for high wind speeds and low sun elevations

Summary and conclusions (2)

- retuned direct albedo affects heating of earth's surface via changed absorption of direct solar flux

- it also affects shortwave atmospheric absorption via changed reflected solar flux

- dominant is the effect on surface temperature, modifying its diurnal cycle and affecting other physical processes like convection

- it can be important in assimilation cycle because of its systematic character

- effect of retuned direct albedo on shortwave atmospheric absorption is only weak

References

Briegleb, B. P., et al., 1986: Comparison of Regional Clear-Sky Albedos Inferred from Satellite Observations and Model Computations. *J. Climate Appl. Meteor.*, **25**, 214–226.

Gardner, A. S., and M. J. Sharp, 2010: A review of snow and ice albedo and the development of a new physically based broadband albedo parameterization. *J. Geophys. Res.*, **115**, Art. F01009/(15 pp).

Hansen, J., et al., 1983: Efficient Three-Dimensional Global Models for Climate Studies: Models I and II. *Mon. Wea. Rev.*, **111**, 609–662.

Payne, R. E., 1972: Albedo of the Sea Surface. *J. Atmos. Sci.*, **29**, 959–970.

Taylor, J. P., et al., 1996: Studies with a flexible new radiation code. II: Comparisons with aircraft short-wave observations. *Quart. J. Roy. Meteor. Soc.*, **122**, 839–861.

Yang, F., et al., 2008: Dependence of Land Surface Albedo on Solar Zenith Angle: Observations and Model Parameterization. *J. Appl. Meteor. Climatol.*, **47**, 2963–2982.