Generalizing cloud overlap treatment to include solar zenith angle effects on cloud geometry

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COSMO, Cracow 2008

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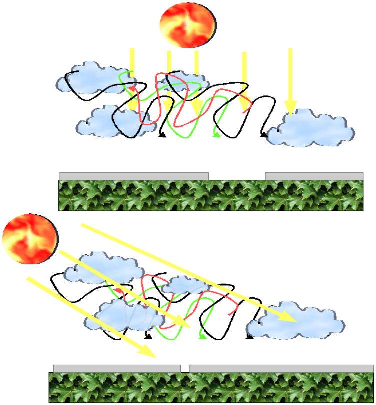
Tompkins A. M. and F. Di Giuseppe. Generalizing Cloud Overlap Treatment to Include Solar Zenith Angle Effects on Cloud Geometry. Journal of the Atmospheric Sciences. 64, 2116 – 2125. (2007)

Outline

SW Radiative Transfer in clouds

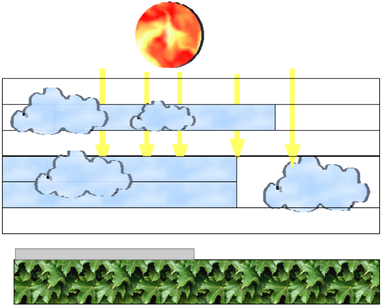
Problem: modelling the photon interaction with a 3D cloud field.
Several “geometrical” aspects need to be considered:



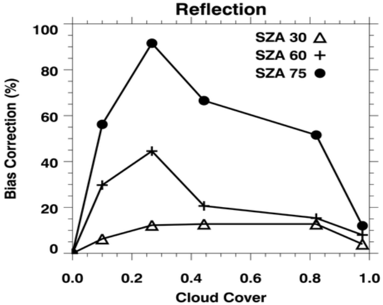
1. spatial arrangements of clouds element
2. vertical overlap
3. sun position

Representation of clouds in GCM

GCMs represent the previous two scenes in the same way regardless of the sun position



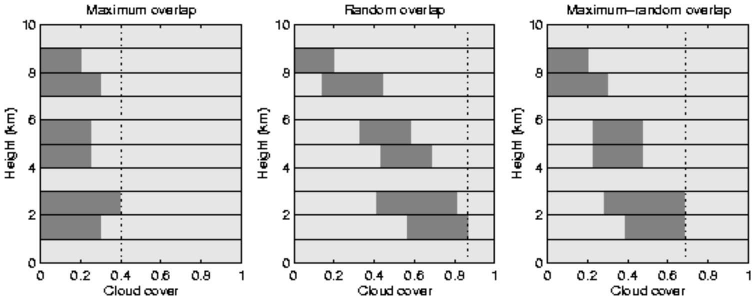
At each vertical layer the cloud is represented in terms of a cloud fraction. The vertical arrangement is established following overlap rules. The sun position is only accounted for by rescaling the photon path length.
2 effects are neglected: the horizontal transport of photons and the effective increase of cloud cover at lower sun angles.



% bias correction of **PP** by **TICA** compared to **benchmark 3D** MC calculation: sun low=error from geometry, sun high error from 3D scattering

Di Giuseppe, F., and A.M. Tompkins, 2005: Impact of Cloud Cover on Solar Radiative Biases in Deep Convective Regimes. , 62,1989 — 2000

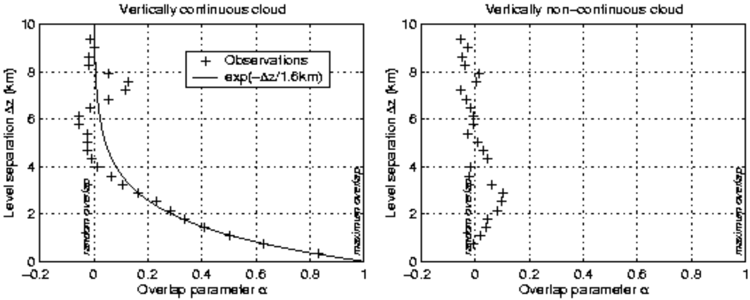
Overlap rules



1. maximum overlap: $C_{i,j}^{MAX} = max\{C_i, C_j\}$ i.e. min Cloud Cover (CC)
2. random overlap: $C_{i,j}^{RAN} = C_i + C_j - C_i * C_j$
3. max-ran overlap: adjacent layer=max overlap, non-adjacent layer=ran

Hogan approach

EXP-RAN overlap: Using as proxy RADAR data (Hogan and Illingworth (2000)) proposed a decorrelation length L_0 (approx 2 km) for continuous clouds.



$$C_{i,j}^{EXP-RAN} = \alpha C_{i,j}^{MAX-RAN} + (1-\alpha) C_{i,j}^{RAN}$$

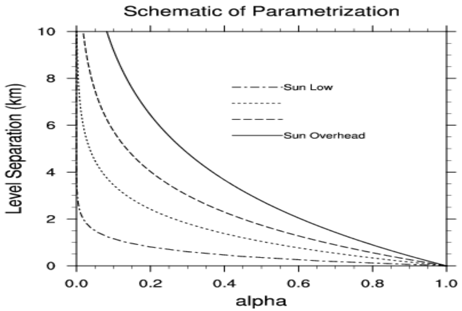
where: $\alpha = exp(-\frac{\Delta z}{L_0})$

Parameterising solar zenith angle effects

The new parametrisation represents the solar zenith SZA (θ_0) effect on apparent cloud geometry by extending the schemes EXP-RAN of Hogan, so that:

$$L = K(\theta_0)L_0$$

The new scheme is called EXP-SZA-RAN.
Assuming L_0 the decorrelation length-scale for the sun overhead case. We need a parametrisation for $K(\theta_0)$



Assumptions for the new parametrisation

1st axiom

As the sun approaches the horizon, cloud elements are randomly overlapped, that is, the vertical de-correlation length-scale should tend to zero

2nd axiom

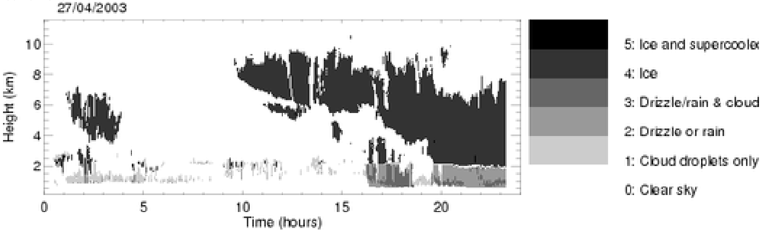
The second axiom governs the rate at which the limit of random overlap is achieved as the sun descends. Three simple parametrisation are tested:

$$K = \begin{cases} 1 - \frac{2\theta_0}{\pi} & \text{"linear": parametrisation 1} \\ cos(\theta_0) & \text{"cosine": parametrisation 2} \\ e^{-J\ tan(\theta_0)} & \text{"exp-tan": parametrisation 3} \end{cases}$$

parametrisation 3 is based on an empirical fit by Hogan et al. to wind-sheared cirrus cloud

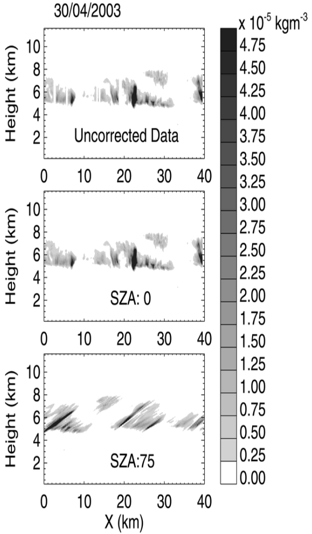
DATA

Radar retrievals from the CloudNet EU project which provided almost continuous observations between the April to November 2003 at Chilbolton, England and between March 2003 to September 2004 at Palaiseau, France are used.



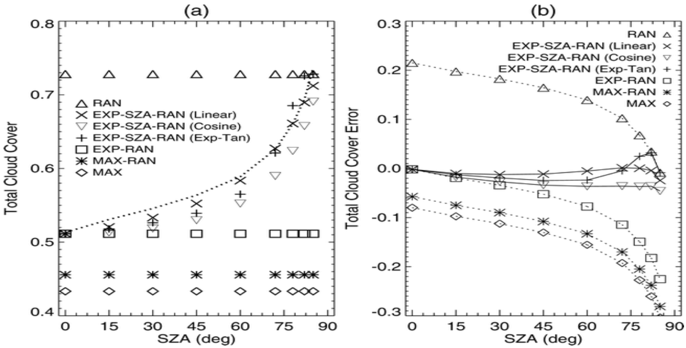
Radar classification field from typical day (27/04/2003) of the Chilbolton radar retrieval. These scenes are split into 2.25 hour segments, which are equivalent to an approximate dimension of 40km assuming a uniform horizontal advection velocity of $5ms^{-1}$

Methodology



- Missing data points corrected if possible, or scene discarded
- Only scenes with 5% $< CloudCover <$ 80% are considered
- Horizontal sub-cloud inhomogeneities are removed (plane parallel)
- Scenes are shifted using the SZA for the **TICA benchmark** simulation.
- L_0 chosen from data to given correct total cloud cover when sun overhead (L_0=4.0km)
- Radiative calculations made with scheme of Morcrette (1991) as used in ECMWF operational model in 2005.

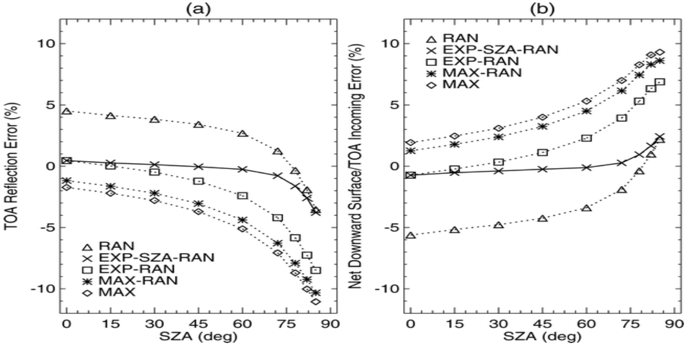
Total Cloud Cover (TCC)



TCC vs SZA averaged for over 150 cloud scenes at Chilbolton site. The true TICA TCC reference is shown by the dotted line on the left.

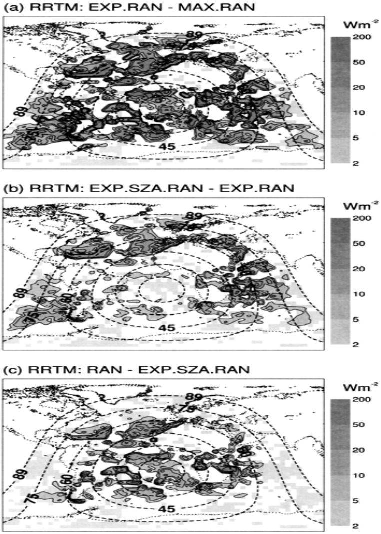
1. Random overlap is good approximation for low sun angles
2. The linear parametrization fits the cloud cover the best

Impact on radiative biases



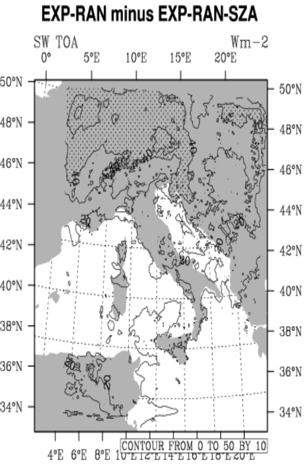
The new scheme greatly reduces the net bias (wrt TICA) integrated over all sun angles compared to the standard overlap schemes

ECMWF's implementation



- 3D calculations repeated with Rapid Radiative Transfer Model (RRTM) radiation code (Mlawer and Clough 1997) which is now operational at ECMWF (Scheme choice did not affect the conclusions)
- Panels show effect on TOA SW fluxes in 3 hour forecast of changing progressively MAX-RAN $->$ EXP-RAN $->$ EXP-SZA-RAN (new) $->$ RAN
- new scheme has half impact of EXP-RAN (depends on L_0)
- dynamical feedback limited in year-long integrations (with imposed SSTs)

COSMO's implementation



- Preliminary results from the COSMO implementation. Panel shows effect on TOA SW fluxes in 3 hour forecast of changing EXP-RAN $->$ EXP-SZA-RAN (new)
- new scheme has major impact where sun lower above the horizon (thus it depends on latitude)
- to put into contest:
  in March at 12:00 UTC
  $SZA = 45 deg$ at 35N latitude
  $SZA = 60 deg$ at 50N latitude
- Locally, effects as large as 40 Wm-2.

Conclusions

- Hogan generalised the MAX-RAN to the EXP-RAN overlap to account for shearing of continuous clouds
- We have further generalised EXP-RAN to the EXP-SZA-RAN to account for the sun position
- The new scheme improves the total cloud cover errors as function of sun angle
- The scheme improves radiative flux/heating rate calculation relative to benchmark TICA calculations
- Parametrisation extremely simple to implement
- The dynamical impact in 3D model was limited - but this is also the case changing from MAX-RAN to Hogan's EXP-RAN. Larger in coupled model?