CLOUD RADIATION PARAMETERIZATION SCHEMES

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1. INTRODUCTION

Basically my talk consist of two parts. In the first one I want to refer the cloud radiation parameterization schemes, with emphazis on cloud parameterization, which can be found in the published literature. These I want to present not in a "narrative manner", but I tried to order the schemes available to emphazise the basic communities and differences. In the second part of my talk,I will present some results of two experiments with the Center's grid-point model, where the radiation models are changed and the radiation forecasts are compared with satellite measurements of the same period.

2. CLOUD PARAMETERIZATION SCHEMES

2.1 Relative Humidity Based

The subgrid scale process cloud formation is intrinsically related to the phasetransition water vapour to liquid water or ice, which takes place when the saturation pressure is reached or, removing its complicated temperature dependance, the relative humidity is 100%. This is valid only on a very small length scale compared to the GCM resolution. Looking at larger scale length it is obvious that already at(largescale) relative humidity values less than 100% condensation may take place arising from smallscale fluctuations of the large scale flow.Based on this already Smagorinsky in 1960 proposed the idea to relate the cloud cover to the large scale relative humidity. Since then several parameterization schemes, based on observations and model tunning have been developped reaching a wide range of sophistication. Because this way of calculating cloudiness needs very small computing time and storage, the relative humidity parameterizations are widely used in GCM's and forecast models. For details see Table 1.

One common deficiency of the RH-models is the fact, that clouds are not incorporated explicitly into the hydrological cycle of the dynamical model. Therefore no cloud liquid water content can be computed and an additional parameterization is required.

Table 1 Summary of relative humidity methods for cloud cover diagnosis

"JUMPING'-MODELS	LINEAR RELATIONS	ELABORATE RELATIONS
RH=100% → c=1 GISS, Somerville, 1974	Smagorinsky, 1960	$c = A(\Theta,p)\ RH^2(\Theta,p)$ Θ: latitude, p: pressure, A: empirical function University of California Elsaesser et al 1976
RH=90% → c=1 NWS, after Cox 1978	DWD-short-range forecast-model	$c_h = 1/400(RH-80)^2 \quad RH >= 80\%$ $c_m = 1/1225(RH-65)^2 \quad RH >= 65\%$ $c_1' = 1/400(RH-80)^2 \quad RH >= 80\%$ $c_1 = c_1' \qquad \text{if } \frac{\partial\Theta}{\partial p} \geq -0.07$ $c_1 = 16.67\frac{\partial\Theta}{\partial p} - 0.1167 + \delta\, c_1' \quad \text{if } \frac{\partial\Theta}{\partial p} < -0.07$ $\delta \begin{cases} =1 & RH > 80\% \\ =0 & RH \leq 80\% \end{cases}$ Met. Office, J. Slingo, 1979
RH=100% → c=0.8 GFDL, Manabe & Wetherald, 1980 (1/3 hemispheric model)	$c_1 = 2.4RH-1.6 \quad 0.2 \leq c_1 \leq 0.8$ $= 0.2 \qquad w \leq 2$ cm/sec $c_h = 0.24RH-0.16 \quad 0 \leq c_h \leq 0.16$ NCAR, Schneider, Washington and Chervin 1978	$c = (\max(0,(RH-RH_c)/(1-RH_c))^2$ $RH_c = 1 - \alpha\sigma\ (1-\sigma)(1+\beta(\sigma-\frac{1}{2}))\quad \alpha=2,\quad \beta=\sqrt{3}, \sigma = p/p_s$ $c = 0$ in well-mixed boundary layer ECMWF, Geleyn, 1980 $q_\ell = \gamma \cdot q_s$ liquid. water mixing ratio q_s = saturation mixing ratio
RH=97% → c=1 GFDL, Wetherald & Manabe, 1980 (global model)	$c = 1.25RH - 0.25$ RAND-Corp. (= 2-level UCLA) Gates & Schlesinger, 1977	
	$c = (0.75 + 0.25\ (r-E_{pt})/(r+E_{pt}))\ RH$ Sellers, 1976 r: rainfall rate E_{pt}: total potential evapotranspiration	

2.2 Deterministic Approach

To avoid this deficiency, another way of cloud parameterization, which I want to call the deterministic approach, is used. The basic idea is to incorporate the cloud liquid(or frozen)water into the prognostic system of equations, treating it as a new prognostic variable. Nevertheless the cloud cover has to be derived from this variable by some assumptions.

One example for this kind of approach is the parameterization scheme for non-convective condensation by Sundquist. Here two additional prognostic equations are set up: one for the relative humidity, describing the charing of water substance between moistening of clear areas and condensation in clouds, and one for the liquid water mixing ratio. The first one is necessary because condensation and therefore cloudiness starts, when a prescibed threshold rel. humidity is reached. Cloud cover in this model is related linearily to the prognostic rel. humidity.

A similar is the one of Ogura and Takahashi, which is described in detail in the proceedings of the Seminar 1977, THE PARAMETERIZATION OF THE PHYSICAL PROCESSES IN THE FREE ATMOSPHERE.

The parameterization of convective cloud cover may also be a member of the deterministic category. Here the cloudiness is derived from the output of a convection scheme.

One example is the Kuo convection scheme, where the fractional cloud area is calculated as the ratio of moisture convergence to the surplus of total moist static energy of the cloud to the environment.

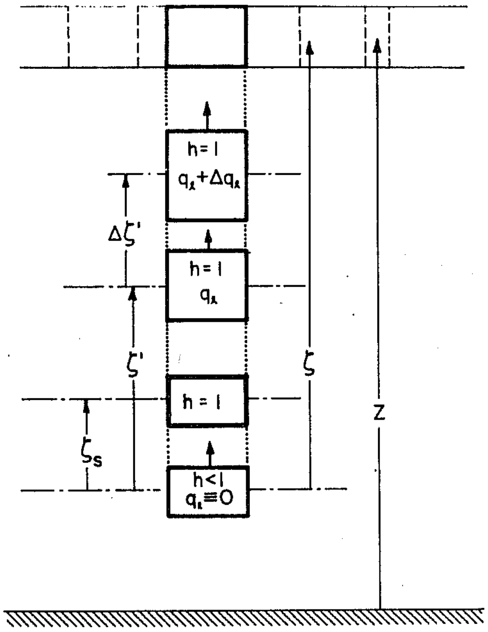
Another possibility is to relate the convective cloud cover to the convective mass flux(Arakawa& Schubert). A linear relationship is used in the tropical circulation model of the Meteorological Office, the constant of proportionality different over land and ocean areas.

2.3 Statistical Approach

In contrast to the last category I want to describe at last two statistical parameterizations, which involve explicitly the small scale fluctuation, which form subgrid scale cloudiness.

The common feature of both models is the derivation of a probability density function for the fluctuations. With the aid of this distribution function it is possible to compute from the local, subgrid scale variables the grid seize averaged quantities.

The first model is that developed by Sasamori, which may be used in a coarse GCM-grid. The local, subgrid model is an airparcel , which is displaced vertically, thereby reaching the condensation level and forming liquid water, a cloud and also precepitation. Then it is possible to write the rel. humidity, liquid water content etc.,as a function of this vertical displacement length and to find the grid seize averaged values as ensemble means of the local variables. (fig.1)



h = h(ζ) relative humidity

$q_\ell = q_\ell(\zeta)$ liquid water mix

$$\langle q_\ell \rangle = \int_{-\infty}^{z} q_\ell(\zeta)\Theta(\zeta-\zeta_s)P(\zeta)d\zeta$$

$$C = \int_{-\infty}^{z} \Theta(\zeta-\zeta_s)P(\zeta)d\zeta$$

$$\Theta(x) = \begin{cases} 0 & x \leqslant 0 \\ 1 & x > 0 \end{cases}$$

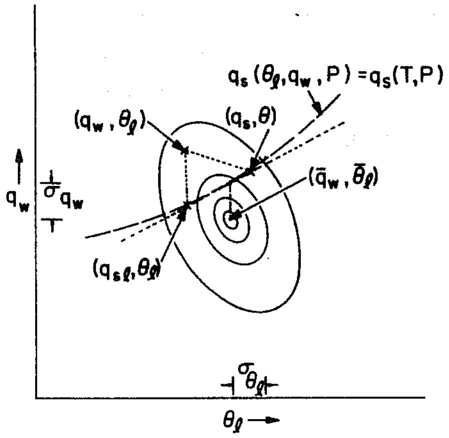
Fig. 1 Schematic description of Sasomori's (1975) model for cloud cover and cloud liquid water content.

The problem is to find the appropriate distribution function. Sasamori solved this by assuming a high correlation between the vertical displacement and the vertical velocity, which means knowing the statistics of w is knowing it of the displacement.

The second statistical cloud parameterization model was published by Sommeria and Deardorf for use in a small(or meso) scale cloud model. In this model predictive equations are available for the mean water substance mixing ratio and its variance , the liquid water potential temperature and its variance as well as the correlation between both variables.

Now the distribution function for the local (sub-grid scale)values is assumed to be Gaussian since both variables are conservative quantities.

(fig.2)



$$\bar{q}_\ell = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} (q_w-q_s)\,\Theta(q_w-q_s)\,G\;dq_w\,d\Theta_\ell$$

$$C = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \Theta(q_w-q_s)\,G\;dq_w\,d\Theta_\ell$$

Fig. 2 Schematic description of Sommeria and Deardorff's (1977) model for cloud cover and cloud liquid water content.

There are two reasons why this parameterization cannot be applied directly to a coarse GCM grid:

a) in the presence of precipetation, which removes water substance from the grid volume, both variables are not conservative quantities anymore and therefore

b) the assumption of a Gaussian distribution is not valid anymore

3.A CLOUD RADIATION INTERACTION EXPERIMENT

In a joint experiment of the Center and our Institut in Köln 4 ten day forecasts had been made: two using as initial fields the observation of February 15.,1976 and the other those of August 25.,1975. Each of the two runs at each distinct date differs only in the radiation model used: one is the standard, operational model and the other the one, which was developed at Köln for the German Weather Service(DWD). Then we compared the forecasted radiation fields with satellite measurements (NOAA) of the same period.
In the following some of the February results will be presented.

3.1 Globally averaged, 10-day mean values(table 2)

The IR-energy loss agrees very well between both radiation calculation and compared to the observation.
The planetary albedo differs to some extend,which may have two major reasons:

a) different treatment of the vertical structure of partial cloudiness (EC:max. overlap, Köln: random positioned)

Table 2 Summary of the radiation results for the comparative experiments described in Section 3

EC	KÖLN	NOAA	
4.59 W/m^2 517.3 $[W/m^2]^2$	- 13.32 W/m^2 219.2 $[W/m^2]^2$	(+16.71) 5.56 W/m^2 493.9 $[W/m^2]^2$	Energy balance, p=0, 10 d, global global mean of zonal variances
- 240.45 W/m^2 109.0 $[W/m^2]^2$	- 240.02 W/m^2 125.2 $[W/m^2]^2$	(-228.4) 241.59 W/m^2 281.0 $[W/m^2]^2$	IR- Emission, p= 0, 10 d, global global mean of zonal variances
31.35 % 0.00529 $[\%]^2 \cdot 10^4$	35.42 % 0.00283 $[\%]^2 \cdot 10^4$	(34.59) 34.13 % 0.00750 $[\%]^2 10^4$	planetary albedo, 10 d, global global mean of zonal variances
- 55.84 W/m^2 176.4 $[W/m^2]^2$	- 56.26 W/m^2 287.7 $[W/m^2]^2$	(climatological data for February)	IR radiation balance, 10 d, global, surface global mean of zonal variances
174.24 W/m^2 833.3 $[W/m^2]^2$	133.21 W/m^2 1865.5 $[W/m^2]^2$		-global radiation, 10 d, surface global mean of zonal variances
45.94 % 0.025 $[\%]^2 \cdot 10^4$ 59.30% 0.032 $[\%]^2 . 10^4$	58.30 % 0.037 $[\%]^2 \cdot 10^4$		cloud cover, 10 d, global global mean of zonal variances
max. overlap	random positioned		

b) a systematic bias in the Köln-model towards clouds which reflect to much energy.

The NOAA observations may have a systematic bias also towards higher planetary albedos (0.5-0.7 nm reflectance equals planetary albedo).

3.2 Zonally averaged, 10-day mean values (fig. 3,4,5)

The IR- emission shows again a close agreement between the two calculations and the observation, except in the tropics, where the height of the radiating cirrus clouds is too low or the calculated emissivity is too small.

The planetary albedo shows the same behaviour as mentioned above.

3.3 Globally averaged, time dependend values (fig. 6,7,8,9)

Since the initial cloud field is diagnosed from the objectively analysed initial moisture field, which is very smooth, the clouds are not in local equilibrium with radiation. Therefore an adjustment process takes place, which lasts app.3 days using the EC-model and 7-8 days using the Köln-model. This duration depends very much on the vertical treatment of clouds:

the max. overlap cloud cover reaches equilibrium much faster than the respective random positioned cloud cover.

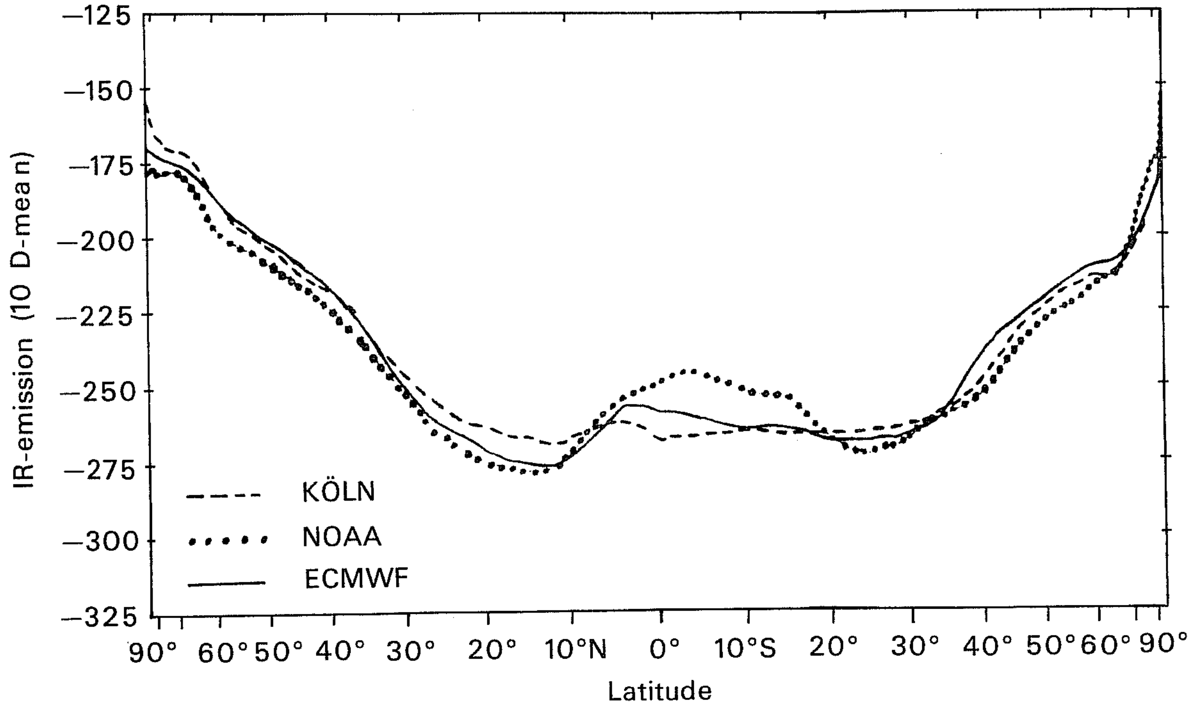


Fig. 3 Meridional distributions of long wave radiative fluxes at the top of the atmosphere.

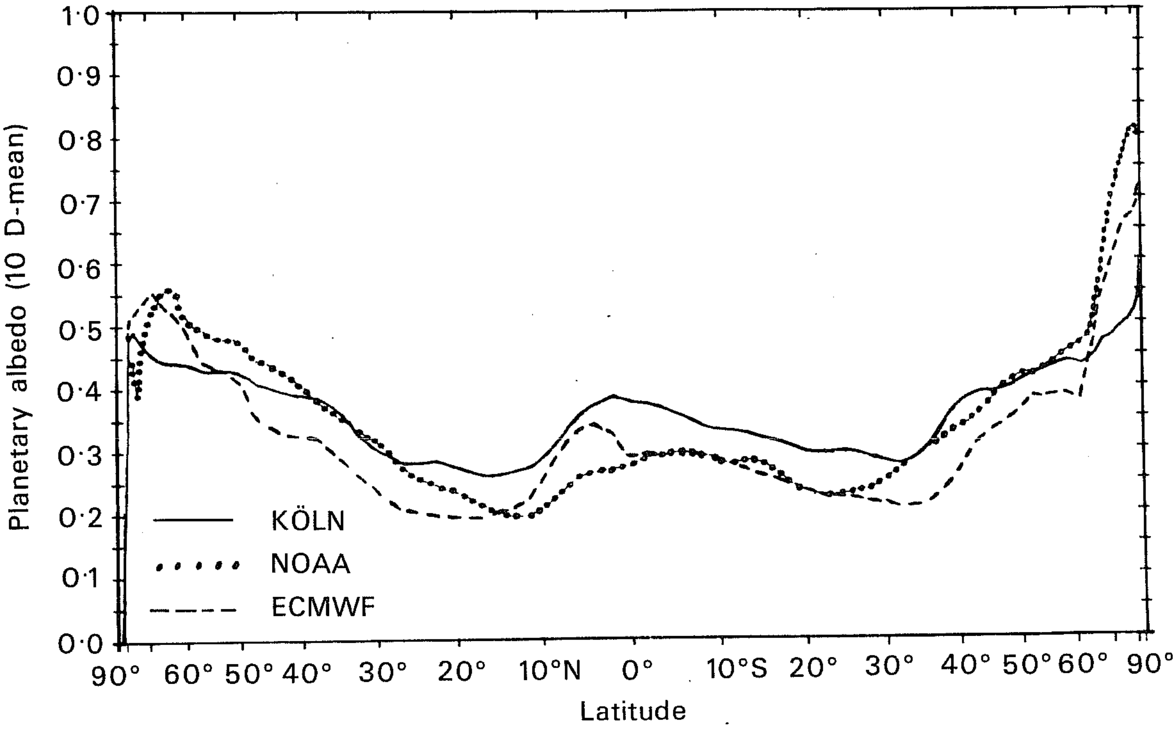


Fig. 4 Meridional distributions of planetary albedos

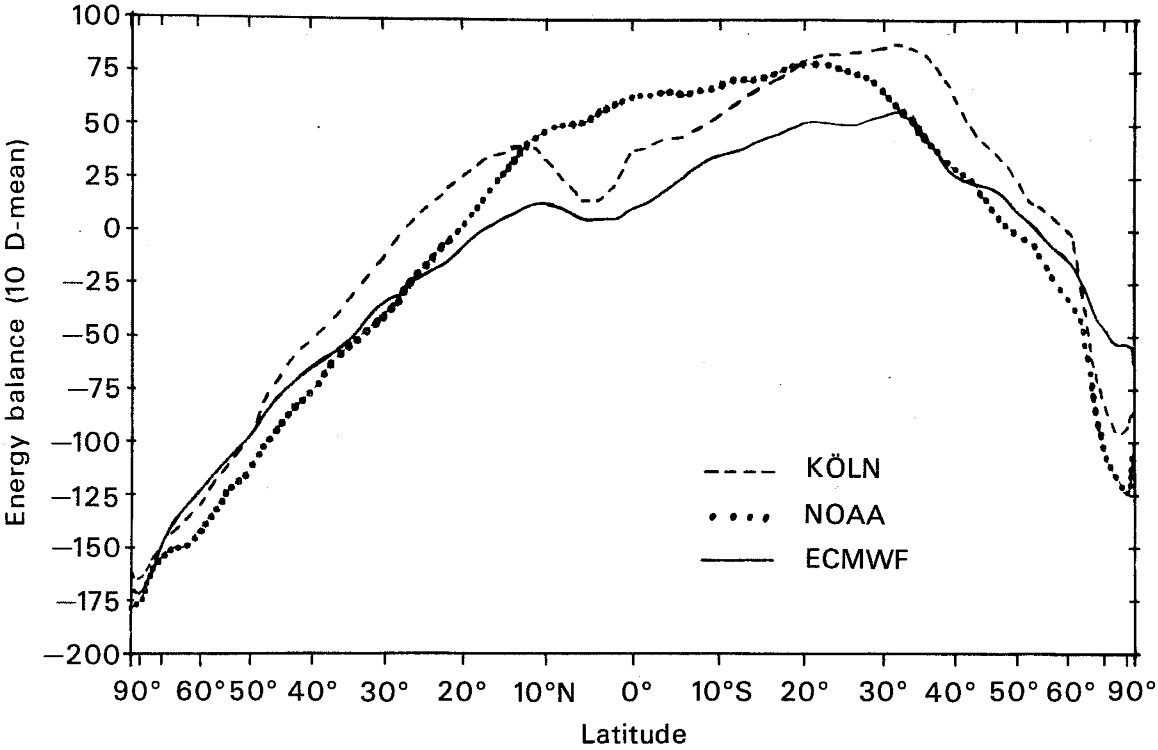


Fig. 5 Meridional distributions of net radiative fluxes at the top of the atmosphere.

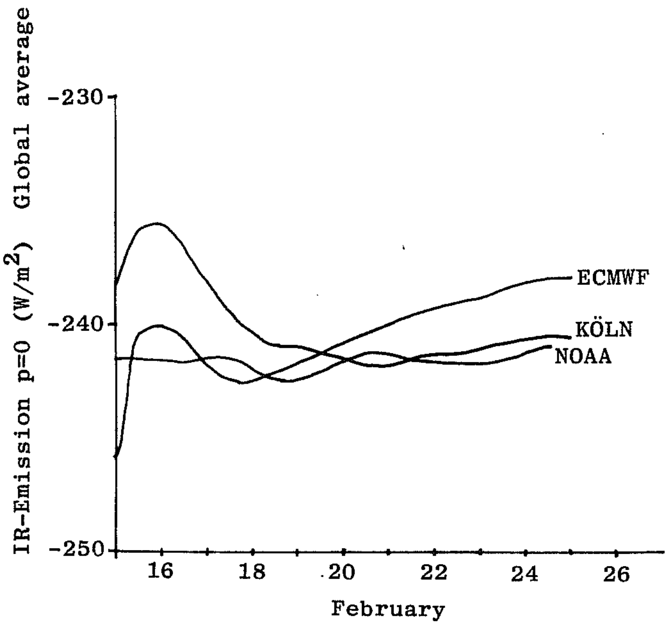


Fig. 6 Time evolution of globally averaged long wave radiative fluxes at the top of the atmosphere.

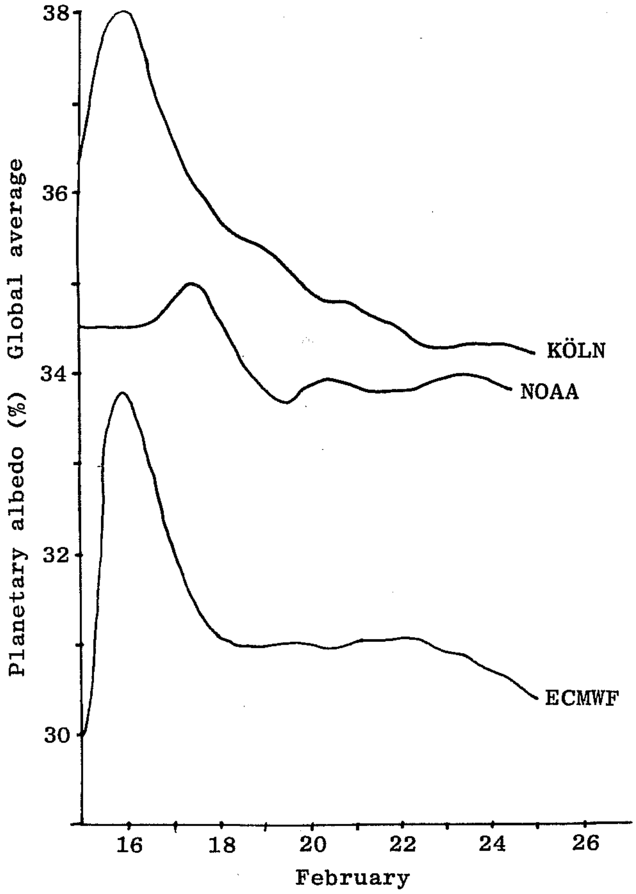


Fig. 7 Time evolution of globally averaged planetary albedo.

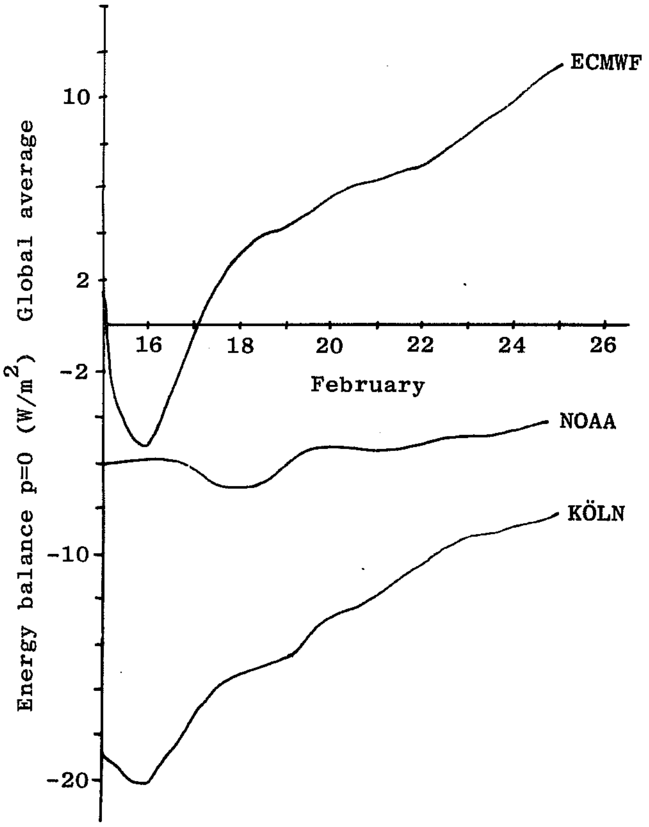


Fig. 8 Time evolution of globally averaged net radiative fluxes at the top of the atmosphere.

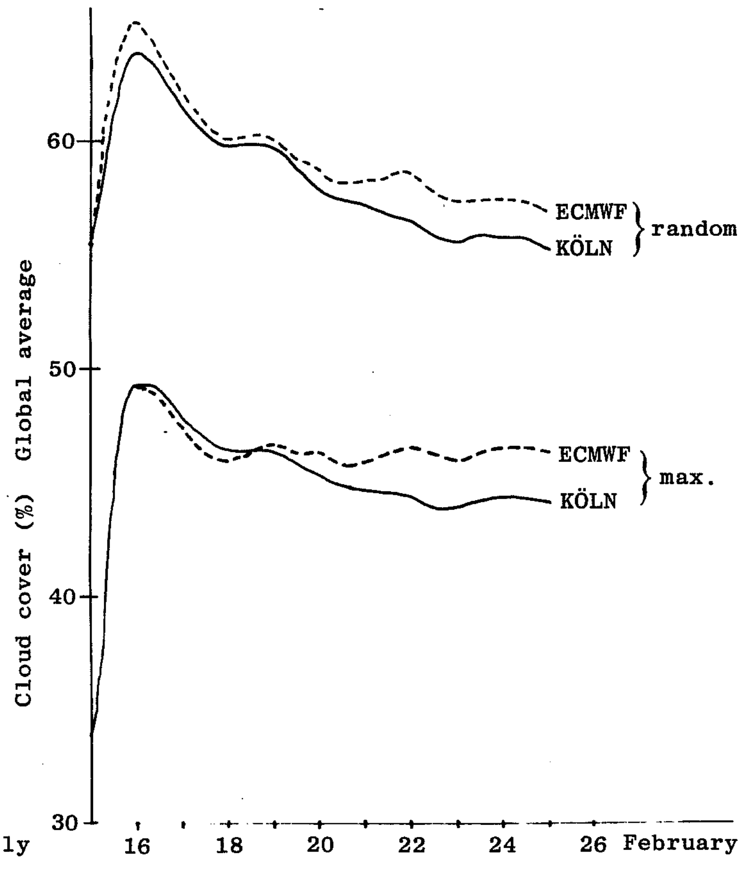


Fig. 9 Time evolution of globally averaged cloud covers computed with two different methods.

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