CLOUD - RADIATION INTERACTIONS

Laura Rontu
Finnish Meteorological Institute

FMI
METEOROLOGICAL
RESEARCH

laura.rontu@fmi.fi

March 1, 1999

CONTENTS:

Influence of clouds on radiation

- Cloud condensate amount
- Size distribution of cloud droplets
- Ice crystals and water droplets

Influence of radiation on clouds

Interaction of cloud and radiation parametrizations in HIRLAM

- Connections of the parametrization schemes
- Predicted and diagnosed variables

Parametrizing effective radius

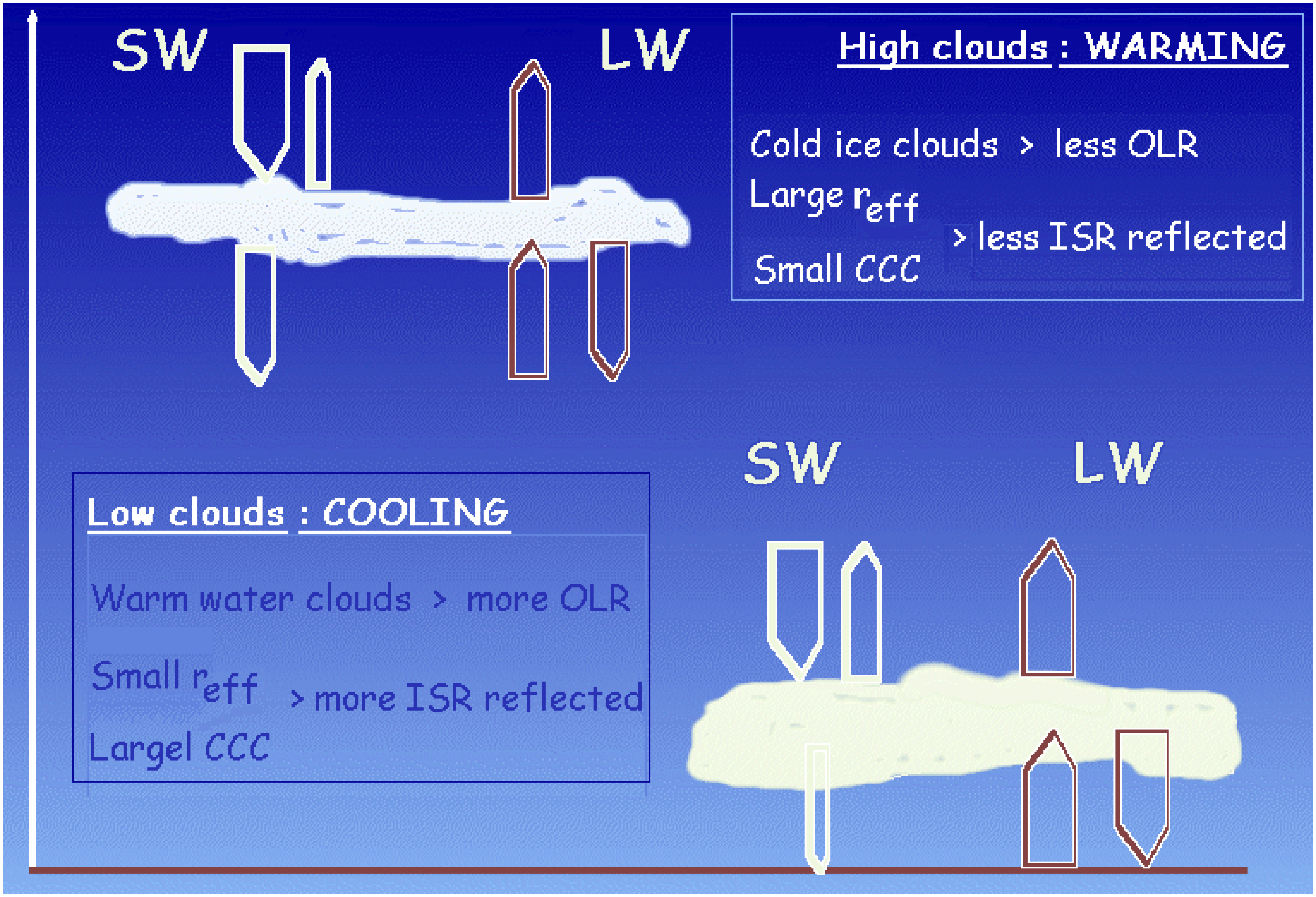
- Definition of r_e
- Short-wave radiation
- Long-wave radiation

Validation

- Problems of validation of radiation parametrizations in cloudy cases
- IRCCM comparisons
- A sensitivity example
- JASIN case
- Jokioinen comparisons
- Influence of radiation on a forecast

Conclusions

INFLUENCE OF CLOUDS ON RADIATION



High clouds : WARMING

Cold ice clouds > less OLR

Large r_{eff}

Small CCC

> less ISR reflected

Low clouds : COOLING

Warm water clouds > more OLR

Small r_{eff}

Largel CCC

> more ISR reflected

Table 1: Global annual mean energy bugdets Wm^{-2} [Kiehl et al(1998)]

Field	Observation	CCM3
	TOA	
OLR	234.8	236.97
Clear sky OLR	264.0	266.22
Solar absorbed	238.1	236.88
Clear solar absorbed	286.3	286.42
LWCF	29.2	29.25
SWCF	−48.2	−49.54
Net TOA	3.3	−0.09
Cloud fraction %	52.2 – 62.5	58.83
	Surface	
Solar absorbed	142 – 168	171.05
Clear solar absorbed	217.2	220.83
Net longwave	45.8 – 66	60.68
Clear net longwave	70.7	92.39
Latent heat	78	89.97
Sensible heat	24	20.47
Net surface	0.00	−0.07

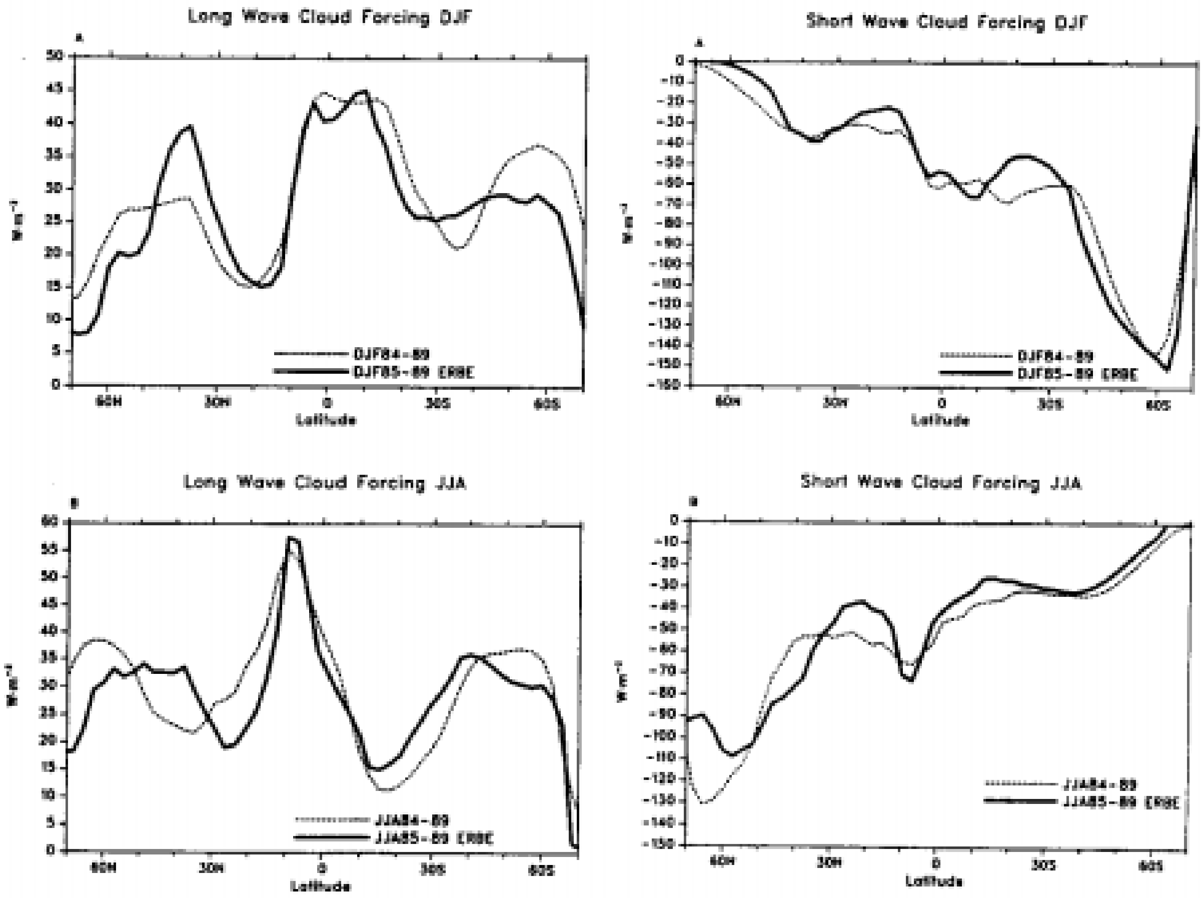


Figure 1: Observed and modelled by NCAR CCM3 cloud forcing

INFLUENCE OF CLOUD DROPLET SIZE ON RADIATION

More pollution → more CCN → more drops → brighter clouds

$$\tau \sim 2\pi N r^2 \Delta z$$

or

$$LWC \sim \frac{4}{3}\pi r^3 N \rightarrow \tau \sim \frac{3LWC\Delta z}{2r}$$

More pollution → more CCN → smaller drops → brighter clouds

Twomey, 1977

But:

LWC ∼ precipitation release

More pollution → more CCN→ more smaller drops → less precipitation → more LWC → brighter clouds *Liou and Ou, 1989*

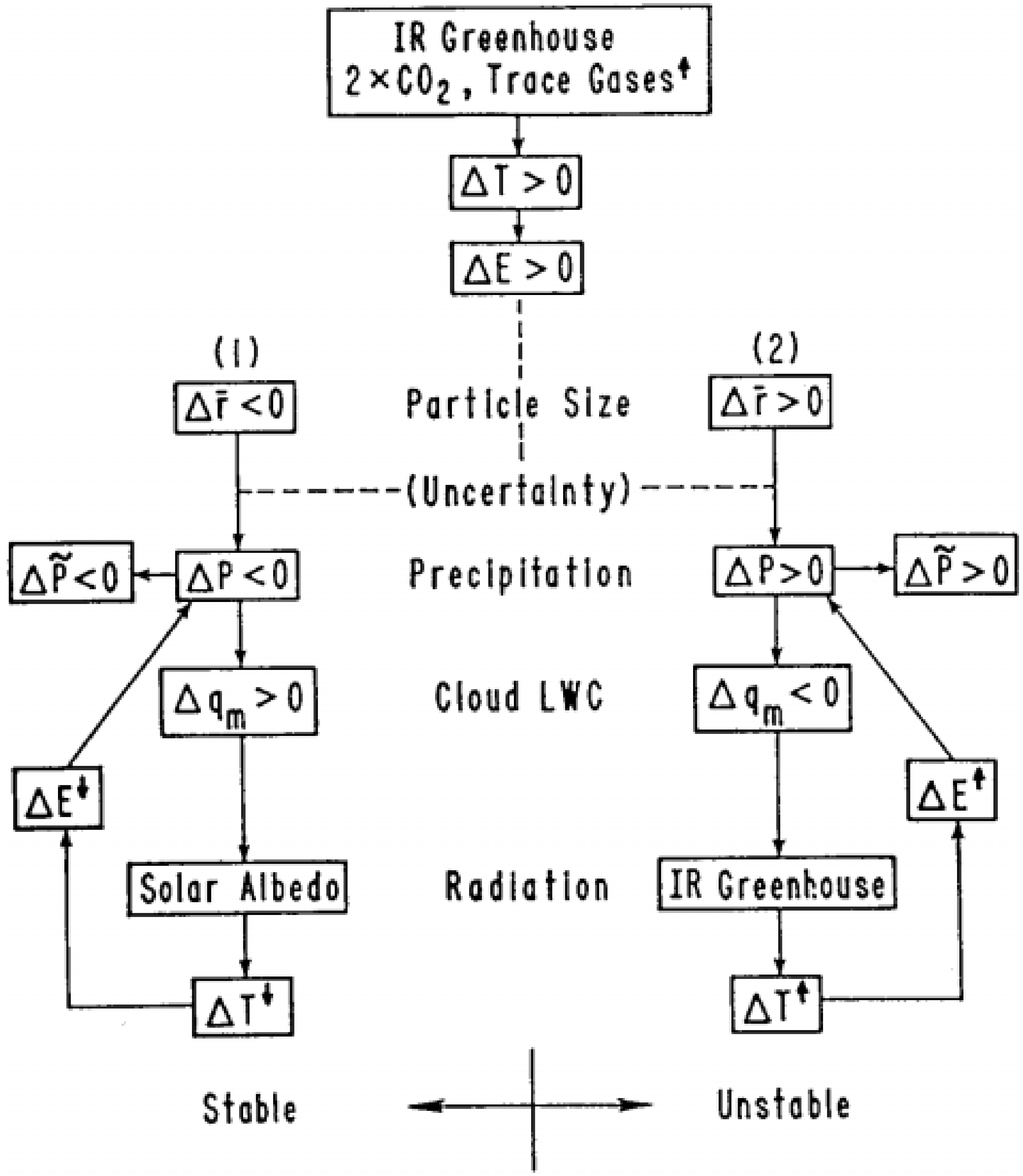


Figure 2: Interactions including cloud particle size ([Liou and Ou (1989)])

INFLUENCE OF RADIATION ON CLOUDS

- Radiative heating/cooling of the surface
  → shallow and deep convection
  → development of fog and stratus
- Radiative cooling of the cloud top
  Radiative heating of the cloud bottom
  → dynamics of stratiform and convective clouds

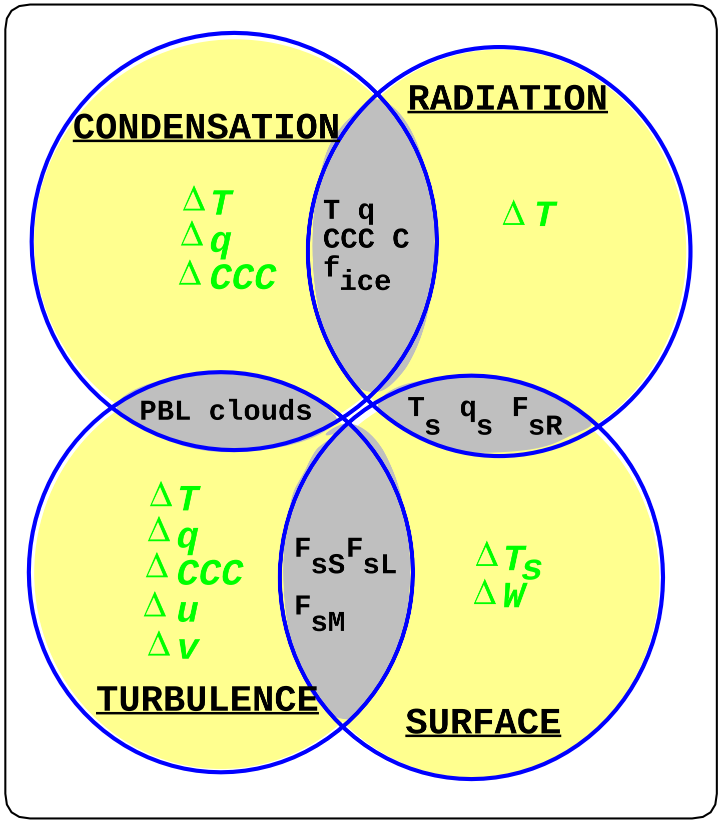


Figure 3: Interactions between the HIRLAM parametrization schemes

Predicted and diagnosed variables

Prognostic equation only for grid volume total cloud water content

Needed also:

Fractional cloud cover

- related to grid size/cloud structure
- diagnosed from humidity separately for convective/stratiform clouds

Rain water

- given by G_p (precipitation release)

Cloud/precipitation ice content

- phase of cloud water diagnosed as f(T)

  e.g. Matvejev (1984)
- used also for precipitation
- melting included

Drop size information

- none

EFFECTIVE RADIUS FOR WATER CLOUDS:

$$r^3_{e,water} = k r_v^3 \tag{1}$$

The parameter k is different for marine and continental clouds.

The cloud condensate content (CCC = liquid + ice water content, in kgm^{-3}) in the cloud is connected to r_v by

$$CCC = \frac{4\pi}{3}\rho_\ell N r_v^3 \tag{2}$$

where ρ_ℓ=1000 kg m^{-3} is the density of liquid water and N the number concentration of the cloud droplets.

Combining (1) and (2) yields

$$r_{e,water} = \left(\frac{3CCC}{4\pi\rho_\ell k N}\right)^{1/3} \tag{3}$$

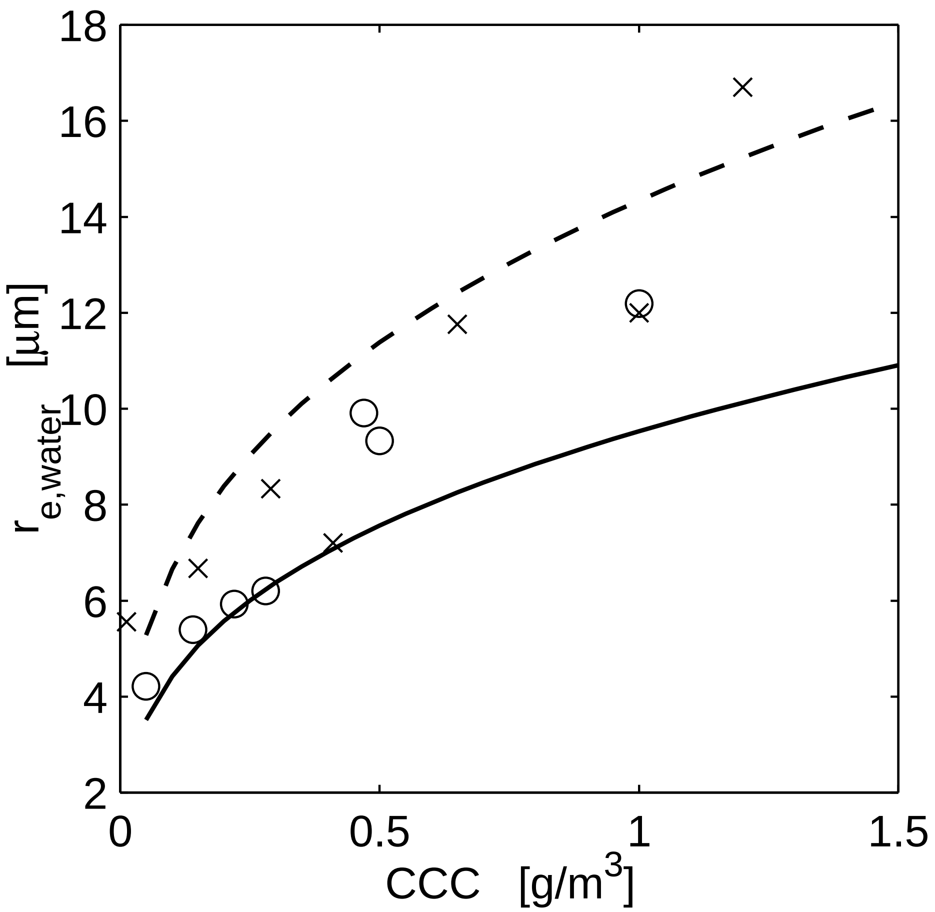


Figure 4: $r_{e,water}$ as a function of CCC for continental (solid) and marine (dashed) clouds ([Wyser et al(1999)])

EFFECTIVE RADIUS FOR ICE CLOUDS:

- sparse observational data about the sizes and shapes of ice crystals
- non-spherical particles

$$D_e = 326.3 + 12.42T_c + 0.197T_c^2 + 0.0012T_c^3, \tag{4}$$

where T_c is in °C and D_e in μm. The effective radius is obtained by simply assuming $r_{e,ice} = D_e/2$.

USING OF EFFECTIVE RADIUS FOR SHORT-WAVE RADIATION PARAMETRIZATION:

$$\begin{aligned} b_{10} &= b_{10a} r_{e,\mathrm{SW}} + b_{10b} \\ b_{13} &= b_{13a} r_{e,\mathrm{SW}} + b_{13b}, \end{aligned} \tag{5}$$

where $r_{e,\mathrm{SW}}$ is the effective radius for short-wave calculations. Values for all the b-parameters are found by adjusting the HIRLAM radiation scheme to a more sophisticated radiative transfer model.

WATER CLOUDS

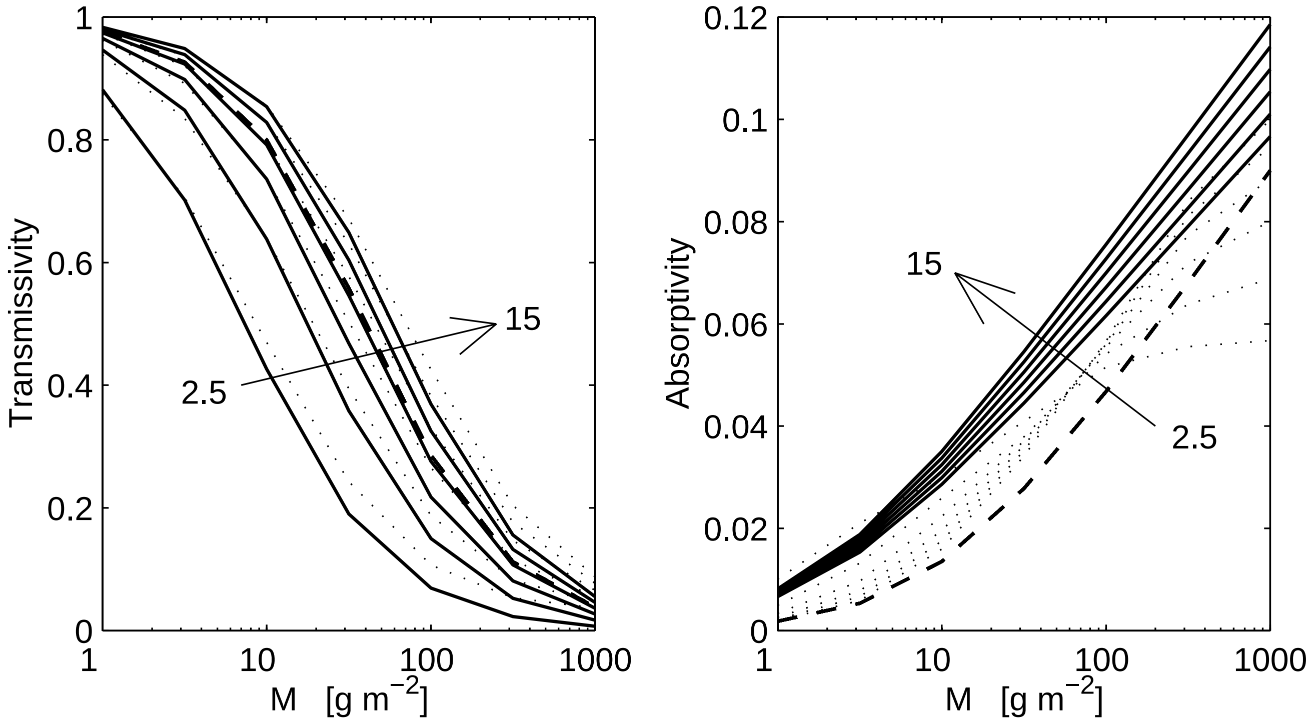


Figure 5: Transmissivity and absorptivity of water clouds as a function of integrated cloud condensate amount M for various $r_{e,water}$ at a zenith angle of 60^o.([Wyser et al(1999)])

ICE CLOUDS

Ice clouds are included in the SW parametrization through an equivalent radius, r_{eq}. An ice cloud with particles of size $r_{e,ice}$ has the same optical properties as a water cloud with $r_{e,water}$=r_{eq}.

An assumption is made for the relation between $r_{e,ice}$ and r_{eq},

$$r_{eq} = a_1 r_{e,ice} + a_2 \cos\theta + a_3 \tag{6}$$

The transmissivity $\hat{T}$ for a number of ice clouds is calculated with the 5-band radiative transfer model with ice optics. The a-parameters are found by matching the HIRLAM transmissivity with the new values for b and $r_e = r_{eq}$ to the result from the radiative transfer model.

PROBLEM: VERTICAL INTEGRATION

The effective radius for the SW calculations, $r_{e,\mathrm{SW}}$, is determined from $r_{e,water}$ and r_{eq}. $r_{e,\mathrm{SW}}$ should be representative not only of the level under consideration, but also of all the cloud water and cloud ice above.

$$r_{e,\mathrm{SW}}(j) = \frac{\sum_{i=1}^{j} \left[r_{e,water}(i)(1 - f_{ice}(i)) + r_{eq}(i) f_{ice}(i)\right] C(i) CCC(i) \Delta z(i)}{\sum_{i=1}^{j} CCC(i) C(i) \Delta z(i)}, \tag{7}$$

where $C(i)$ is the cloud cover and $\Delta z(i)$ the thickness of the layer i.

Using effective radius for long-wave radiation parametrization:

$$k_{a,x} = c_1 + c_2 \exp(-c_3 r_{e,x}) \tag{8}$$

where the index x stands for either water or ice. Expression (8) is taken from ECHAM 4 (Roeckner et al. 1996). The total mass absorption coefficient is composed of water and ice contributions. The effective emissivity ϵ of a cloudy layer now becomes

$$\epsilon = C\{1 - \exp\left[-(k_{a,water} m_w + k_{a,ice} m_i)\right]\}, \tag{9}$$

where $m_w = (1 - f_{ice}) CCC\Delta z$ and $m_i = f_{ice} CCC\Delta z$ are the cloud water and cloud ice amounts (in gm^{-2}) of the layer.

HOW TO VALIDATE A RADIATION SCHEME?

Possibilities and problems

- standard verification
- comparison with line-by-line calculations
- model intercomparisons (ICRCCM)
- comparison with special observations
- fluxes at the top of the atmosphere from satellite data

- surface radiation fluxes + aerological sounding data

  `clear sky:  quite possible (but - point value/grid average - e.g.  albedo in winter forest)`

  `cloudy sky:  where to take the cloud water (adiabatic/diagnostic/model integration)`

Influence of radiation parametrizations in forecast

- one-dimensional model runs
- three-dimensional experiments and parallel runs

Table 2: ICRCCM comparisons

SW down (Wm^{-2})	low thin	low thick	high thin	**high thick**
ICRCCM CS	782±31	-	779±31	-
ICRCCM CL	921±18	537±48	920±18	536±54
H2 old	814	251	853	241
H2 new CS	767	153	760	149
H2 new CL	892	525	930	529
LW down (Wm^{-2})				
ICRCCM CS	399±8	-	360±7	-
ICRCCM CL	389±11	413±3	358±7	363±7
H2 old	409	416	356	371
H2 new CS	408	416	368	371
H2 new CL	378	416	358	371

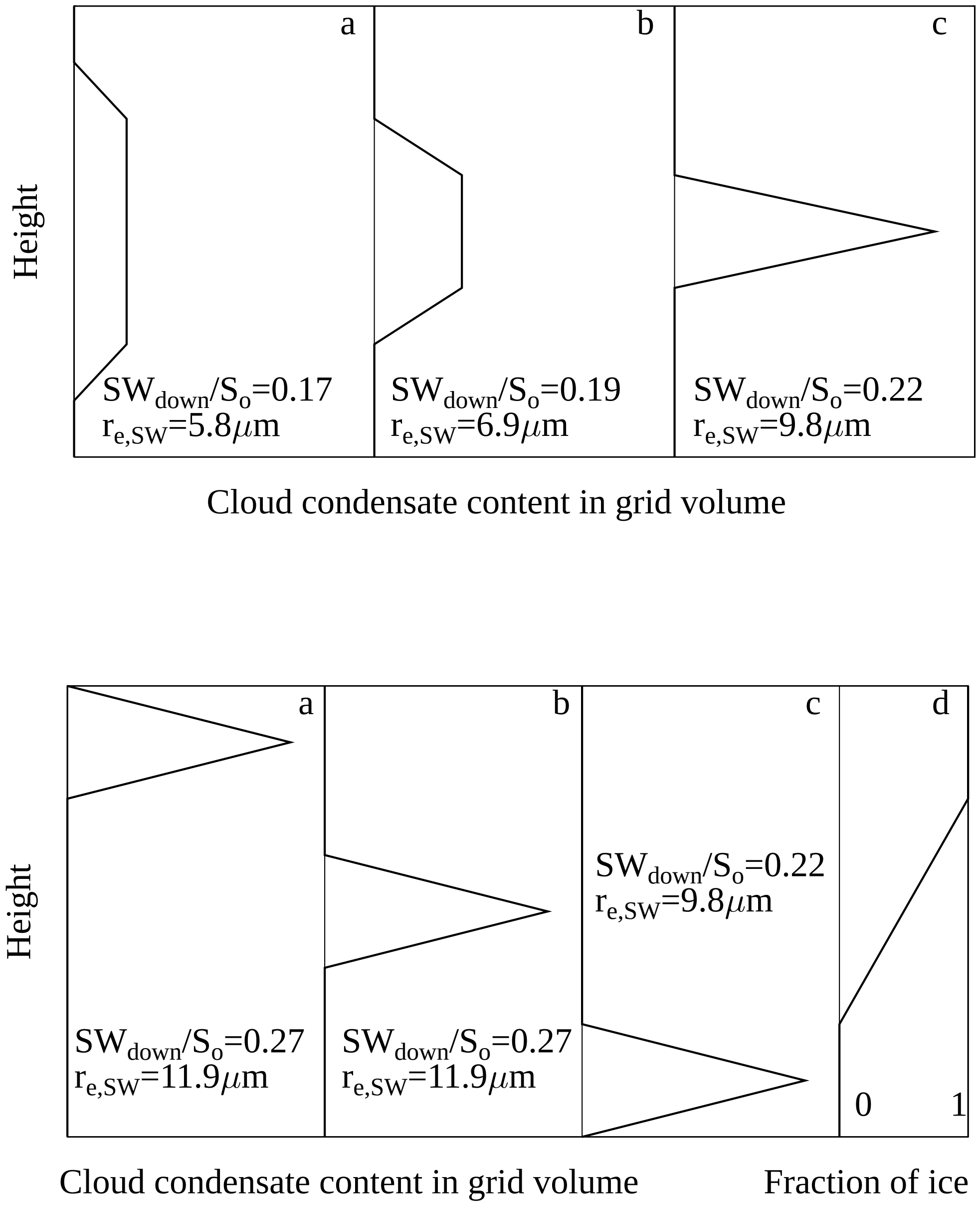


Figure 6: Sensitivity examples

Table 3: Net radiation fluxes in the JASIN case

SW net (Wm^{-2})	Above cloud	In cloud	Below cloud
H2 old	275	205...270	205
H2 new/diagnosed reff	305	230...300	230
H2 new/observed reff	270	200...265	200
Obs*	260±50	210...275±40	200±40
Schmetz*	280	235...255	
LW net (Wm^{-2})			
H2 old	-85	$-7\ldots-10$	-18
H2 new/diagnosed reff	-85	$-8\ldots-10$	-18
H2 new/observed reff	-85	$-7\ldots-10$	-18
Obs**	-70 ± 4	$-10\ldots-20\pm4$	-20 ± 4
Schmetz and Raschke**	-90	0	-20

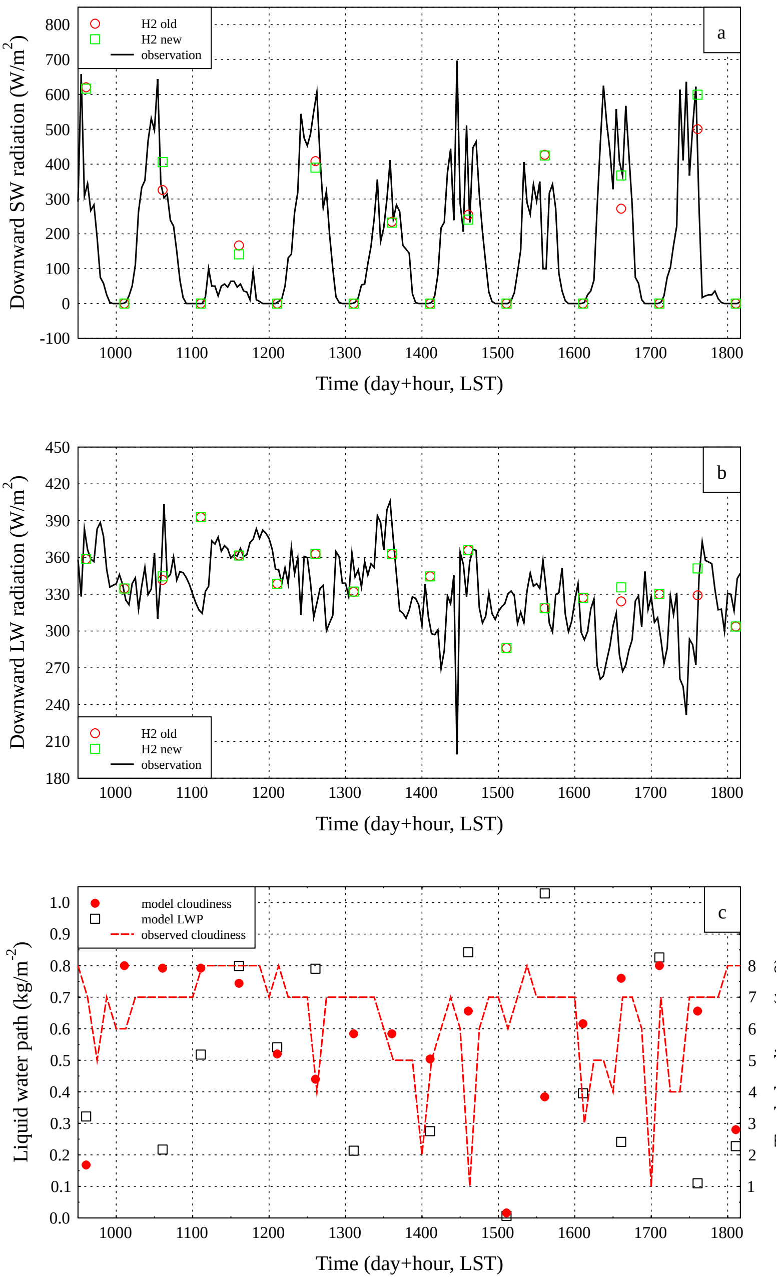


Figure 7: Downward short-wave (a) and long-wave (b) radiation fluxes at Jokioinen from 12 UTC 9 July to 12 UTC 19 July, 1989.

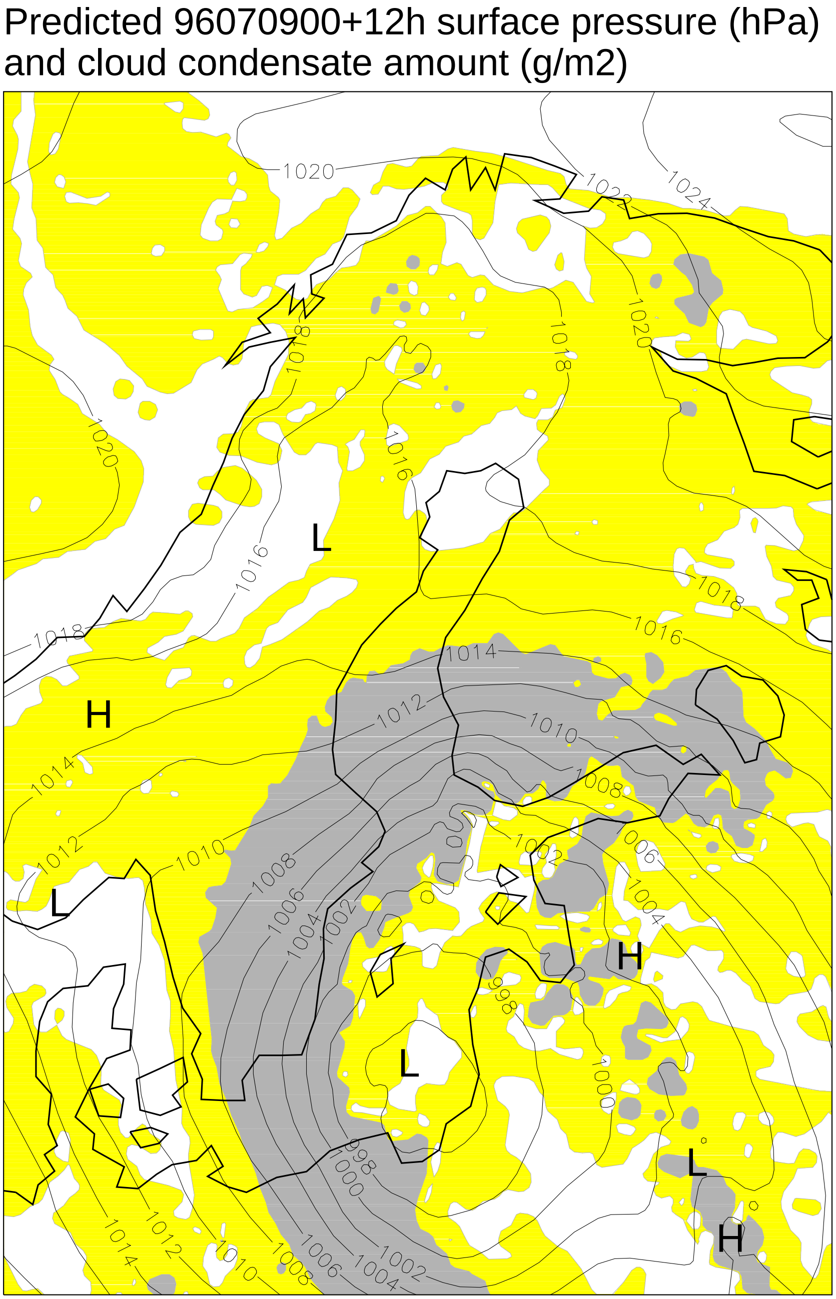
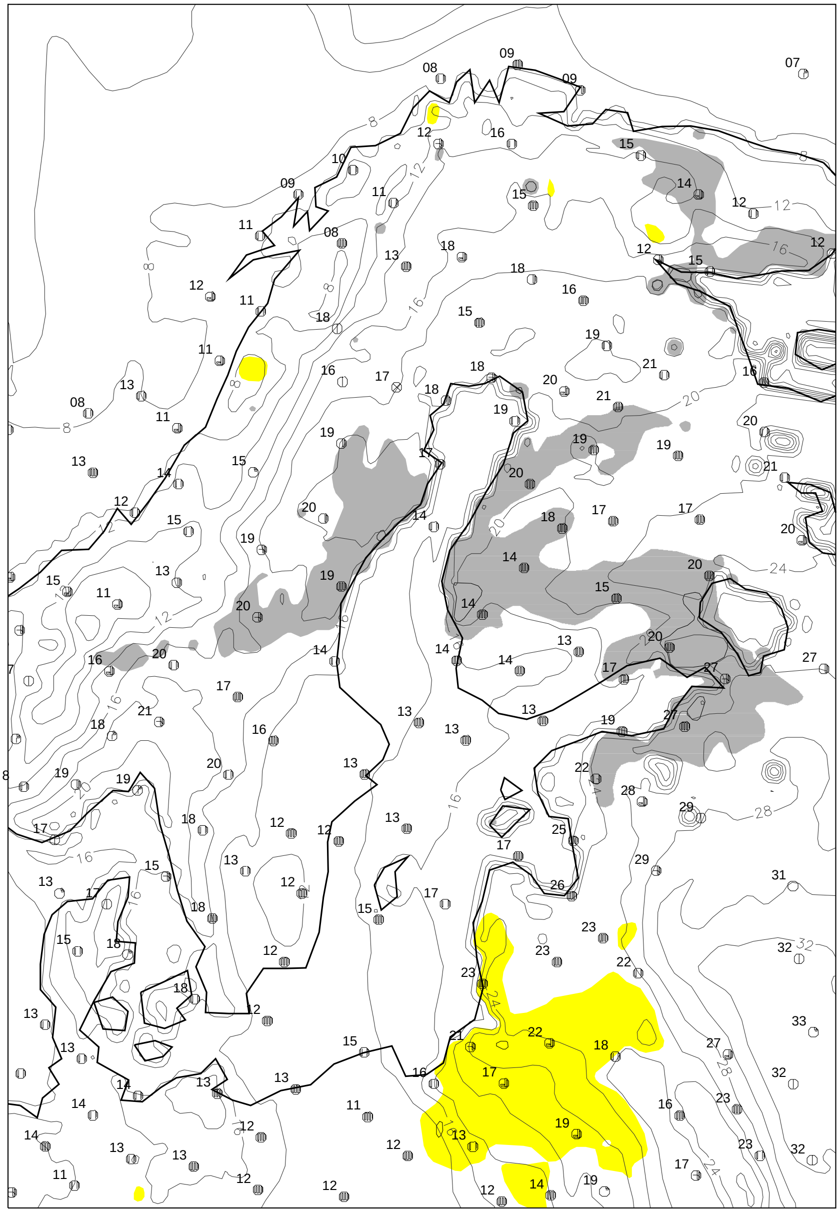


Figure 8: The reference HIRLAM forecast at 00 UTC 9 July 1996 +12h.



Predicted 96070900+12h and observed at 96070912
two-metre temperatures (C)

Figure 9: Two-metre temperature and cloud cover at 12 UTC 9 July

CONCLUSIONS

Importance of consistent cloud and radiation schemes

- **cloud condensate content**
- **cloud ice definition**
- **fractional cloud cover**
- **cloud droplet/crystal size**

The most important thing in the cloud-radiation interactions is to obtain good cloud condensate content/cloud cover forecasts.

Surface radiation flux observations as a tool for model validation (also in cloudy cases).

References

[Kiehl et al(1998)] Kiehl, J.T., J.J. Hack and J.W. Hurrell, 1998: *The energy budget of the NCAR Community Climate Model CCM3.* **J.Climate**, 11, 1151-1178.

[Liou and Ou (1989)] Liou, K.-N. and S.-C.Ou, 1989: *Role of cloud microphysical processes in climate: an assessment from a one-dimensional perspective.* **J.Geoph.Res.,** 94(D6), 8599-8607

[Twomey(1977)] Twomey, S., 1977. The influence of pollution on the shortwave albedo of clouds. **J.Atmos.Sci**, 34,1149-1152. Liou,

[Wyser et al(1999)] Wyser, K., L. Rontu and H. Savijärvi, 1999: *Introducing the effective radius into a fast radiation scheme of a mesoscale model.* Accepted for publication in **Contr. Atm. Phys.**