# RADIATION SCHEME OF HIRLAM

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**CONTENTS:**

## Importance

- Radiation balance of the Earth-Atmosphere system
- Two-metre temperature of HIRLAM

## Equations and methods

- Definitions
- Equation of radiative transfer
- Integrations
- Problems, simplifications and accuracy

## Radiation scheme of HIRLAM

- Method
- Solar radiation
- Terrestial radiation

## Validation

- How to validate?
- Some results

## Conclusions

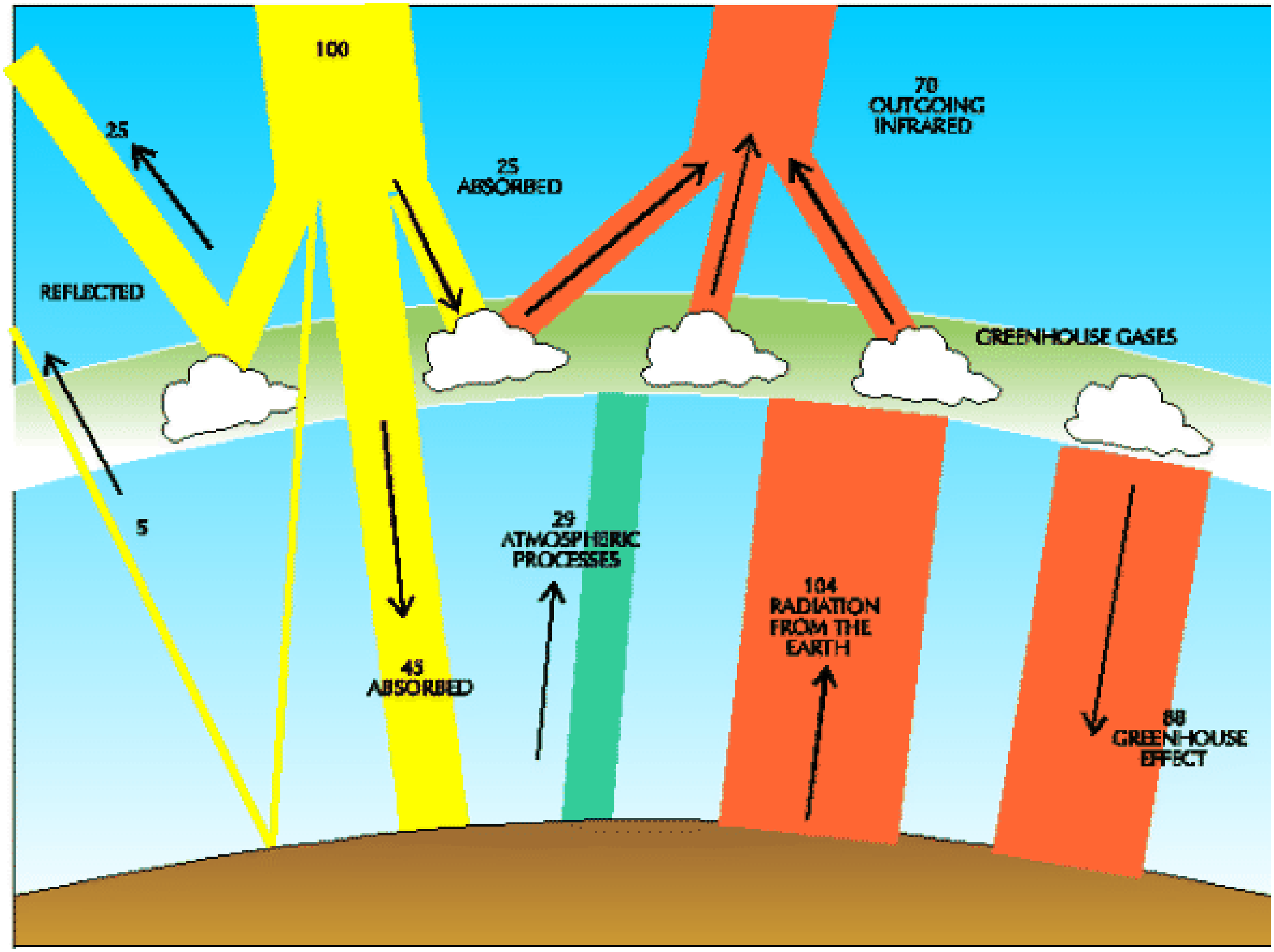
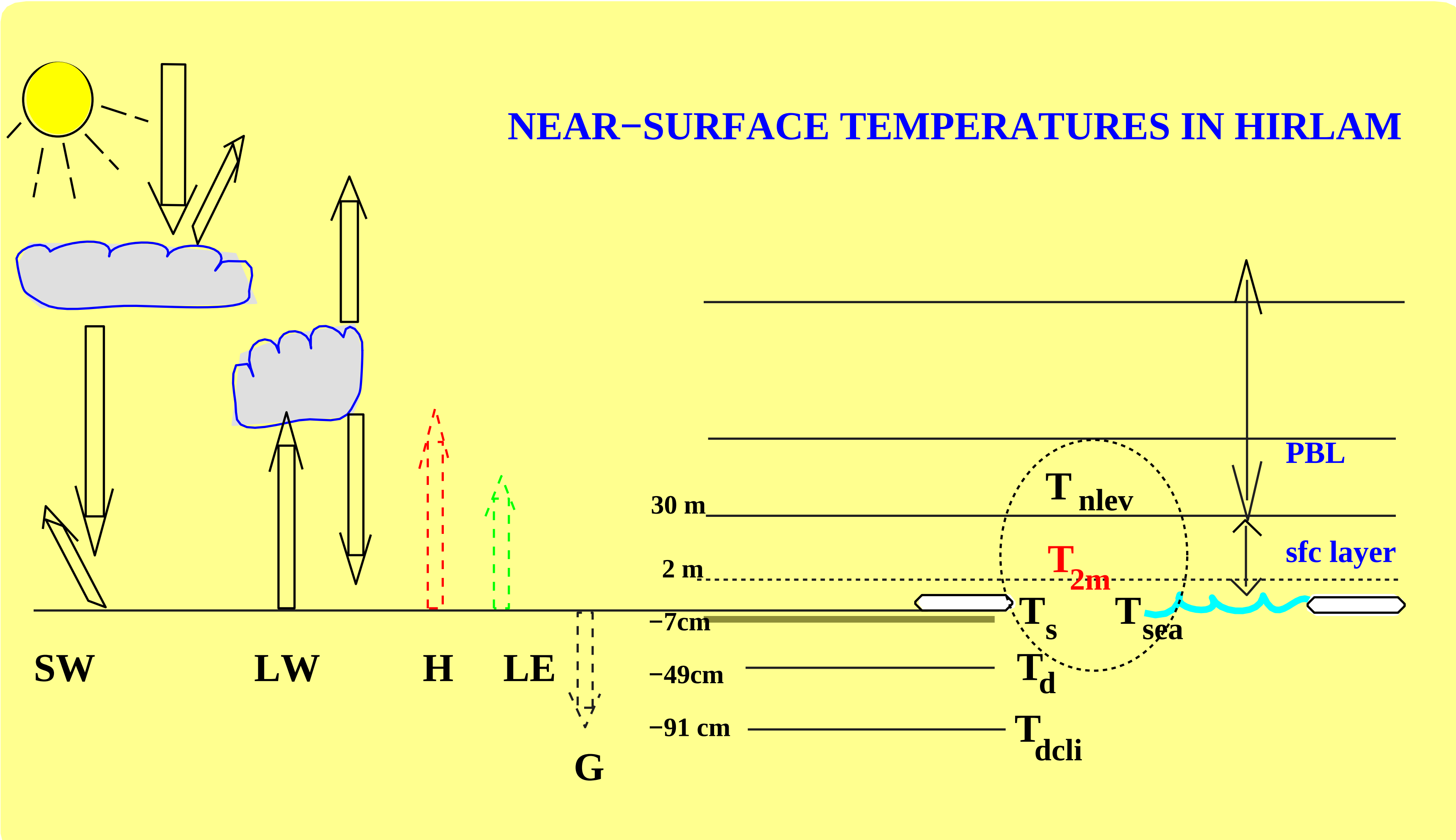



Figure 1: Radiation balance of the Earth-Atmosphere system


NEAR−SURFACE TEMPERATURES IN HIRLAM
PBL
sfc layer
30 m
2 m
−7cm
−49cm
−91 cm
T nlev
T2m
Ts
Tsea
Td
Tdcli
SW
LW
H
LE
G

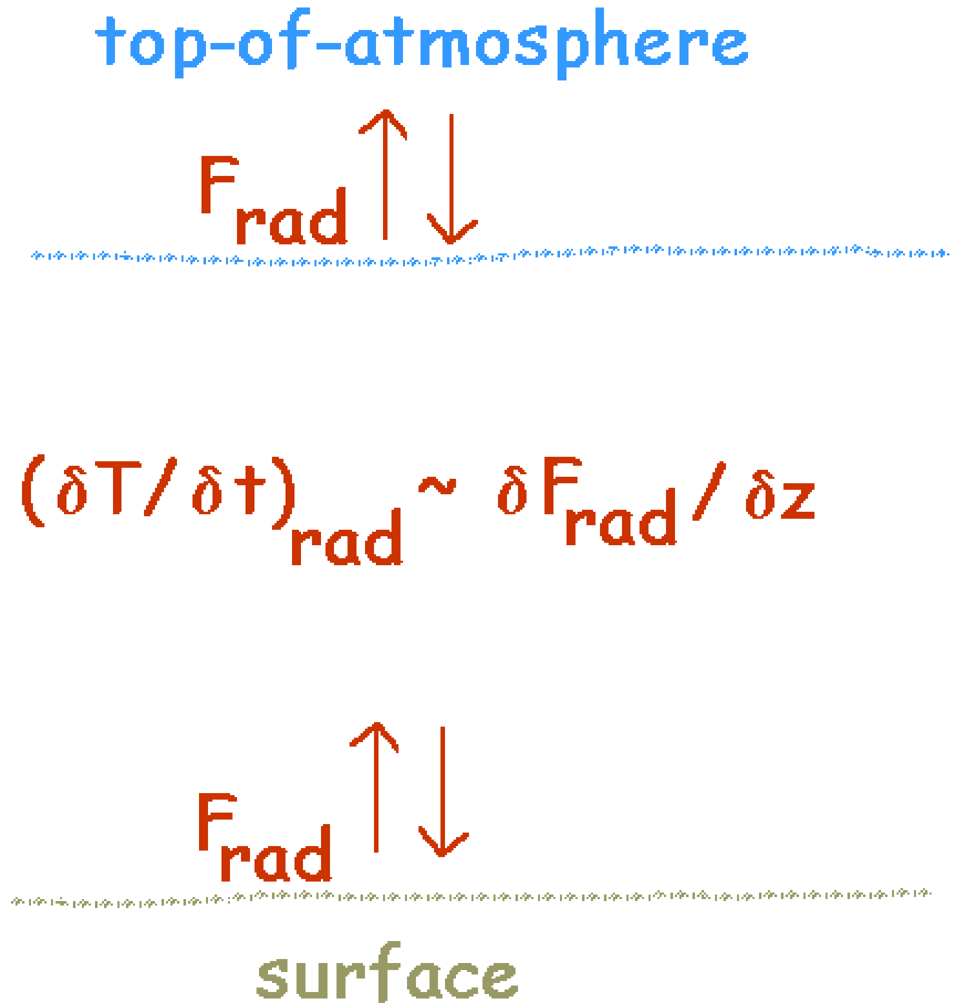



Figure 2: Variables calculated by the radiation scheme

## DEFINITIONS:

### Flux of radiative energy, $F_{rad}$ [$Wm^{-2}$]

$$F_{rad} = \frac{\mathrm{d}^2\mathrm{E}}{\mathrm{dAdt}}, \tag{1}$$

where $A$ is area and $t$ time

### Irradiance, $I_{rad}$ [$Wm^{-2}sr^{-1}$]

### = flux of radiative energy in a defined direction

$$I_{rad} = \frac{\mathrm{dF_{rad}}}{\mathrm{d\Omega cos}\theta}, \tag{2}$$

where $\Omega$ is the space angle and $\theta$ the angle between the normal of the surface and incoming/outgoing radiation

Flux of radiative energy and irradiance for a wave number $\nu$:

$$F_\nu = \frac{\mathrm{dF_{rad}}}{\mathrm{d}\nu} \tag{3}$$

$$I_\nu = \frac{\mathrm{dI_{rad}}}{\mathrm{d}\nu} \tag{4}$$

where $\nu$ [m$^{-1}$] is the wave number, $\nu = 1/\lambda$.

## EQUATION OF RADIATIVE TRANSFER:

Now the **equation of radiative transfer**, with a plane-parallel assumption, can be written as

$$cos\theta \frac{\mathrm{dI}_\nu(\mathrm{z};\theta,\phi)}{\mathrm{k}_{\mathrm{e}\nu}(\mathrm{z})\rho(\mathrm{z})\mathrm{dz}} = -I_\nu(z;\theta,\phi) + J_\nu(z;\theta,\phi) \tag{5}$$

where $z$ is the height of observation, $\theta$ and $\phi$ are the zenith and atsimuth angles of the ray $I_\nu$ and $\rho$ is the air density. The mass extinction coefficient $k_{e\nu} = k_{a\nu} + k_{s\nu}$ is the sum of mass absorption and mass scattering coefficients.

On the RHS of the equation there are

- the sinks $-I_\nu(z;\theta,\phi)$
  = radiation absorbed and scattered by gases, hydrometeors and aerosol particles

- sources $+J_\nu(z;\theta,\phi) \sim k_{s\nu}/k_{e\nu}, P_\nu, I_\nu, B_\nu(T(z)) \ldots$
  = radiation emitted and scattered from other directions by gases, hydrometeors and aerosol particles

influencing transfer of radiation in the direction $\theta$, $\phi$.

If scattering is important, the direct solution of Eq. 5 is not possible. If scattering is not so important, we could try to go through the cycle of four integrations:

**INTEGRATIONS:** Integrate over

1. Optical depth $\tau_\nu$[a] to get
   $I_\nu \uparrow (\tau_\nu; \theta, \phi)$
   $I_\nu \downarrow (\tau_\nu; \theta, \phi)$

2. Angles $\theta$ and $\phi$ to get
   $F_\nu \uparrow (\tau_\nu)$
   $F_\nu \downarrow (\tau_\nu)$

3. Wave number $\nu$ to get upward and downward fluxes

[a] Optical depth for a wave number $\nu$, $\tau_\nu = \int_z^\infty k_{e\nu}(z')\rho(z')dz'$

$F \uparrow (z)$

$F \downarrow (z)$

4. Vertically over $z$ to get the net flux radiative flux and heating at any level

   $F(z) = F \uparrow (z) - F \downarrow (z)$

   $(\frac{\partial T}{\partial t})_{rad} = -\frac{1}{\rho c_p}\frac{\partial F_n}{\partial z} = \frac{g}{c_p}\frac{\partial F_n}{\partial p}$

**PROBLEMS AND SIMPLIFICATIONS:**

Huge number of computations - especially in integrating over the wave number (LBL = line-by-line integrations)

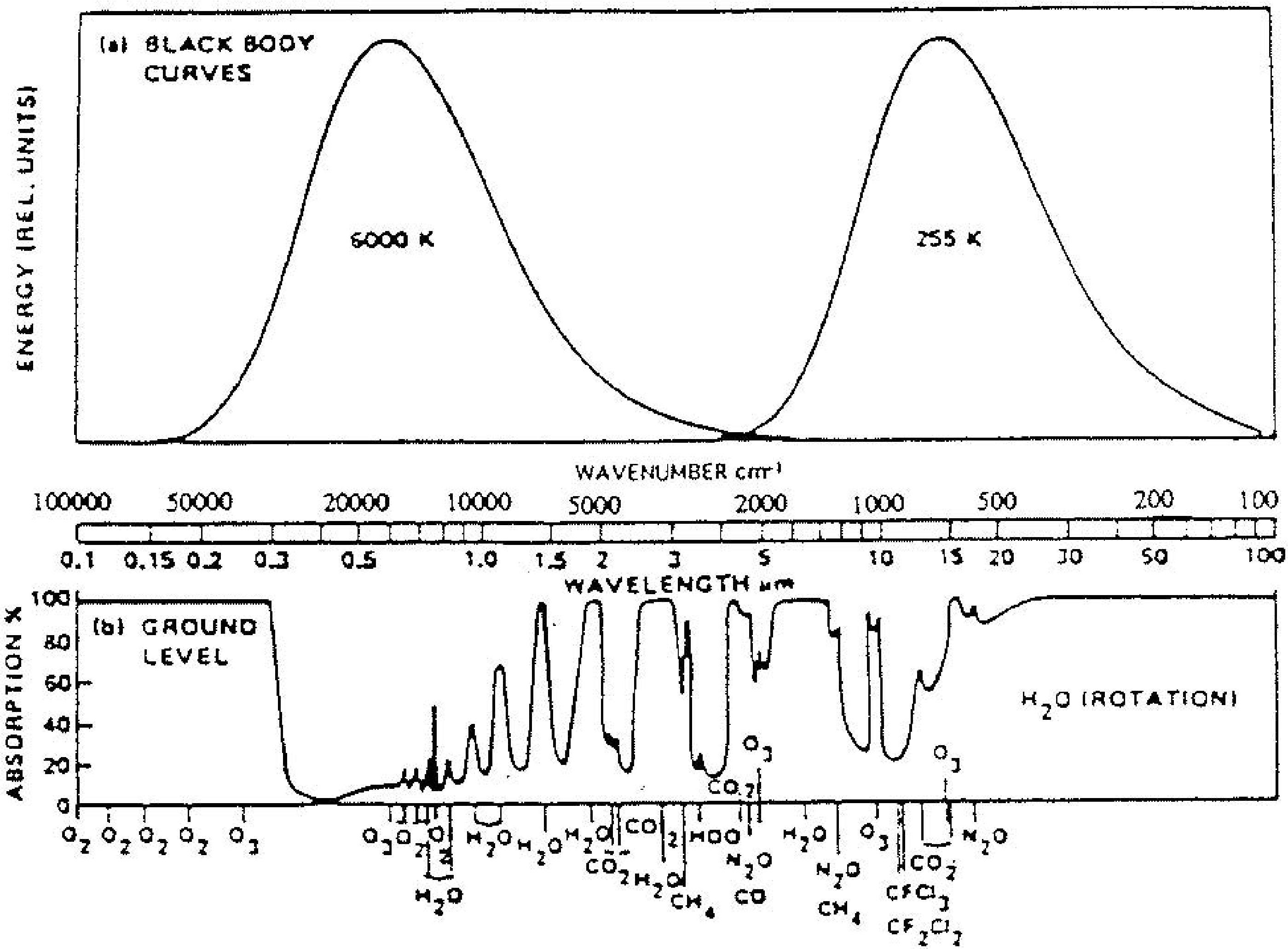



Figure 3: Solar and terrestial radiation

## Detailed information about the Earth-Atmosphere system needed

- temperature distribution $T(z)$
- extinction and scattering coefficients $k_{e\nu}$, $k_{s\nu}$ depending of distribution and properties of atmospheric gases, cloud and aerosol particles
- direction of scattering $P_\nu$
- boundary conditions: solar radiation flux; albedo, emissivity and temperature of the surface

$\Rightarrow$ SIMPLIFICATIONS for NWP models, based on detailed radiative transfer models

**Factors limiting the accuracy of radiation calculations in NWP models:**

1. Information about atmosphere not complete in the model: errors, missing variables and details
2. Optical properties of the atmospheric components not fully known
3. Simplifications due to limited computer resources

## RADIATION SCHEME OF HIRLAM:

**FAST AND SIMPLE!**

Accurate enough for short-range weather prediction

1. Two spectral regions: solar and terrestial radiation
2. Weighted contributions of clear air and clouds to absorption, transmission and emission of radiation
3. Simplified vertical integrations

Resulting:

- Radiation flux $F_{rad}$ at the surface and at the top-of-atmosphere level
- Radiative heating $(\frac{\partial T}{\partial t})_{rad}$ at all model levels

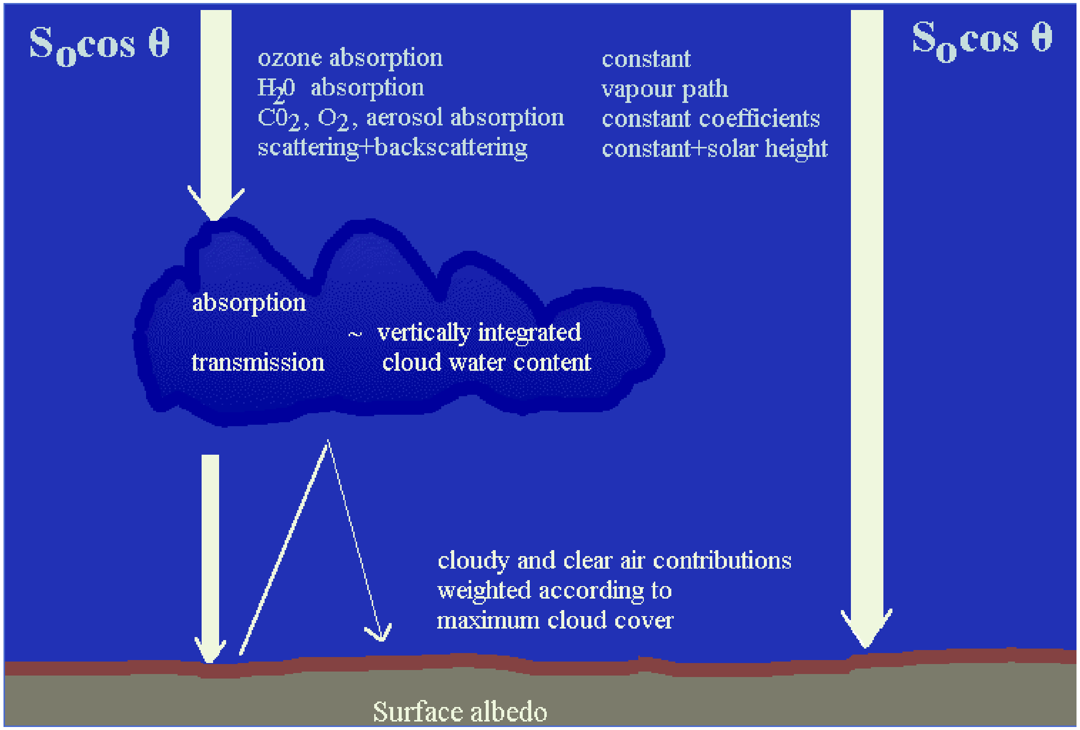



Figure 4: Parametrization of solar radiation

## Cloud short-wawe transmissivity and absorptivity functions

- fits to detailed multiple scattering scheme calculations for stratus-type clouds
- depend on the solar zenith angle $\theta$ and the modified cloud condensate amount $\hat{M}$ (in $\mathrm{g\,m^{-2}}$) [a]

### Absorptivity

$$\hat{A} = b_{10}(b_{11} + \cos\theta)\log(1 + b_{12}\hat{M}) \tag{6}$$

with the parameters $b_{10} = 0.013$ , $b_{11} = 1$, and $b_{12} = 0.1\,\mathrm{m^2\,g^{-1}}$.

### Transmissivity

$$\hat{T} = \hat{T}_1 / \left(\hat{T}_1 + \hat{M}\right) \tag{7}$$

[a] $\hat{M}(z) = C_{max}^{-1} \int_z^{\mathrm{TOA}} CCC(z')C(z')\,dz'$

where

$$\hat{T}_1 = b_{13}(b_{14} + \cos\theta) \tag{8}$$

with the parameters $b_{13} = 40\,\mathrm{g\,m^{-2}}$ and $b_{14} = 0.5$.

Calculated:

- Clear-air solar heating due to water vapour absorption.
- In and below clouds clear-air values reduced by the cloud transmittance $\hat{T}$.
- Extra heating due to cloud drop absorption, represented by $\partial\hat{A}/\partial p$.
- All clouds are considered to consist of liquid water droplets.

## TERRESTIAL RADIATION:

Needed:

$$\left.\begin{array}{r}\text{Temperature}\\ \text{Emissivity}\end{array}\right\} = \left\{\begin{array}{l}\text{at all levels}\\ \text{at surface}\end{array}\right.$$

Broad-band emissivity scheme

| | |
|---|---|
| water vapour line spectrum | $\sim$ vapour path |
| minor contributions | constants |
| clouds | effective cloud cover |

## Water vapour line spectrum

Emissivity $\sim$ water vapour path

$\sim$ vertically integrated specific humidity $q$

| | |
|---|---|
| Emission from level z to space | $+$ |
| Exchange of radiation with the surface | $+$ |
| Exchange of radiation between all layers | $-$ |
| $\Rightarrow$ | |
| Exchange of radiation between cloud layers | $+$ |

No integrations between all model levels

(calculations $\sim$ n instead of $\sim$ $\mathrm{n}^2$)

## Long-wave radiation and clouds:

Cloud emissivity $\epsilon_c \sim 1$ - exp[-$\alpha$(z) * CCC]

Fractional cloud cover C

$\Rightarrow$ Effective cloud cover $C_{eff} = \epsilon_c * C$

Dependency on height of the mass absorption coefficient $\alpha$(z)

$\rightarrow$ smaller values for ice clouds.

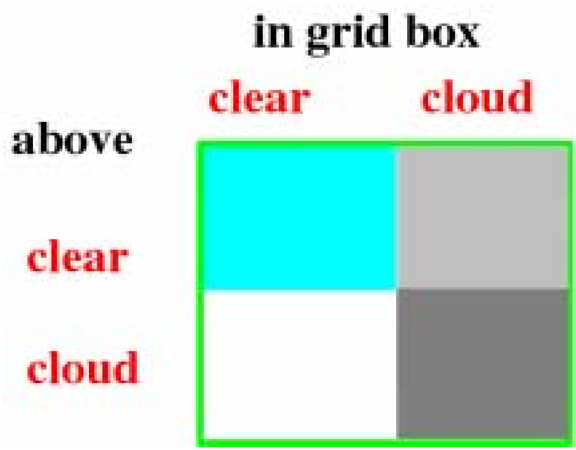



Figure 5: Long-wave calcluations in a grid box

## Minor contributions

Effect of $CO_2$,$O_3$, water vapour continuum included as constant terms

## Long-wave radiative flux at surface

- Flux from all atmospheric layers
- Flux from maximum effective cloud 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**

## Some results

- **comparison with line-by-line calculations**
- **three-dimensional experiments and parallel runs**
- **fluxes at the top of the atmosphere from satellite data**
- **standard verification**

Radiative heating: mid-latitude summer, clear sky, zenith angle 30 deg

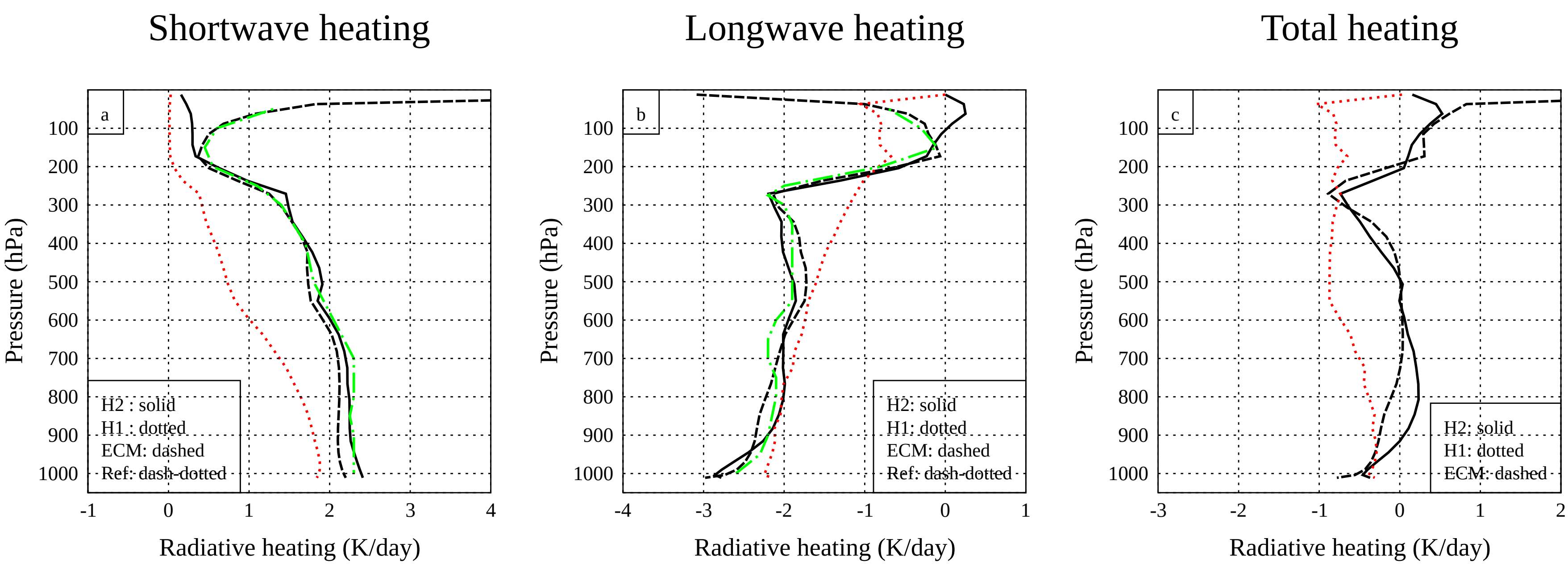



Figure 6: IRCCM comparison with line-by-line calculations [Sass et al.(1994)]

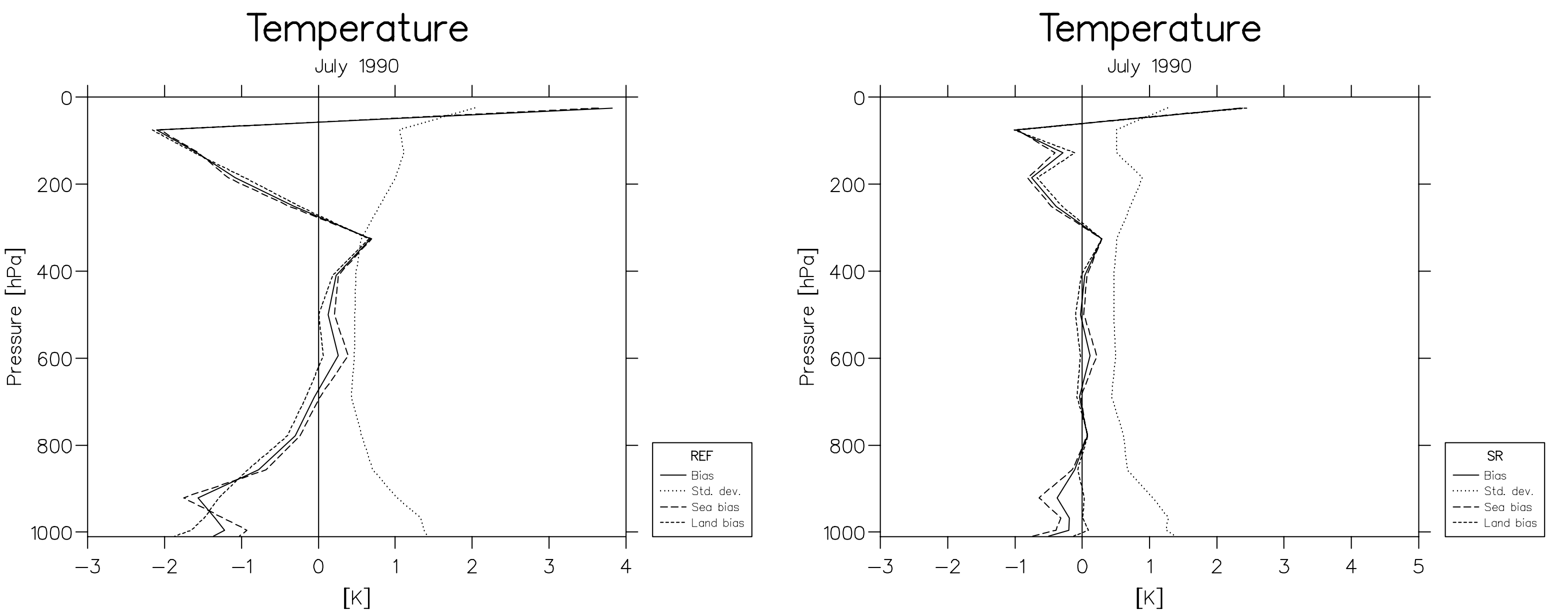



Figure 7: Old and present HIRLAM radiation scheme compared in a climate mode run[Sass et al.(1994)]

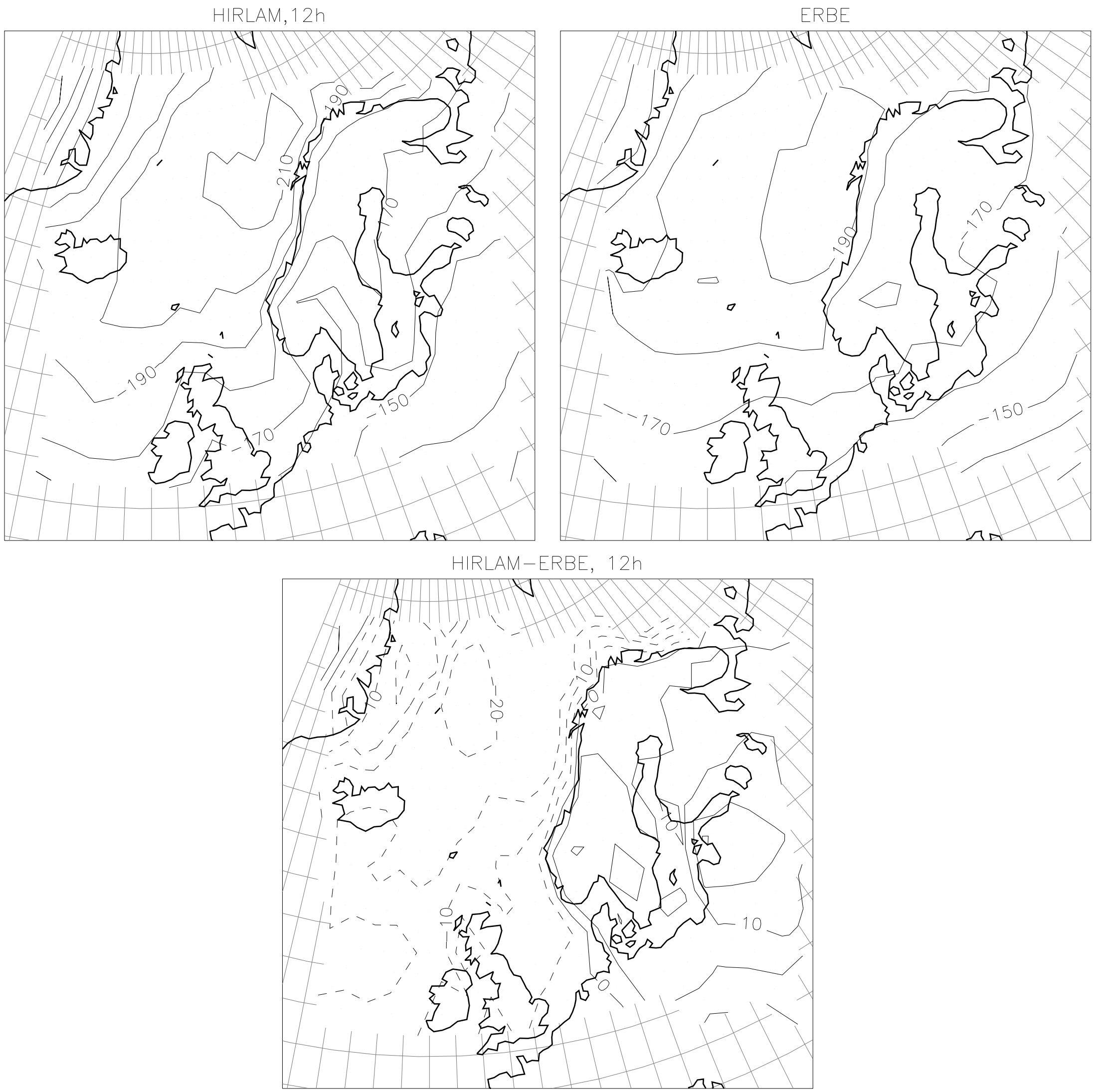
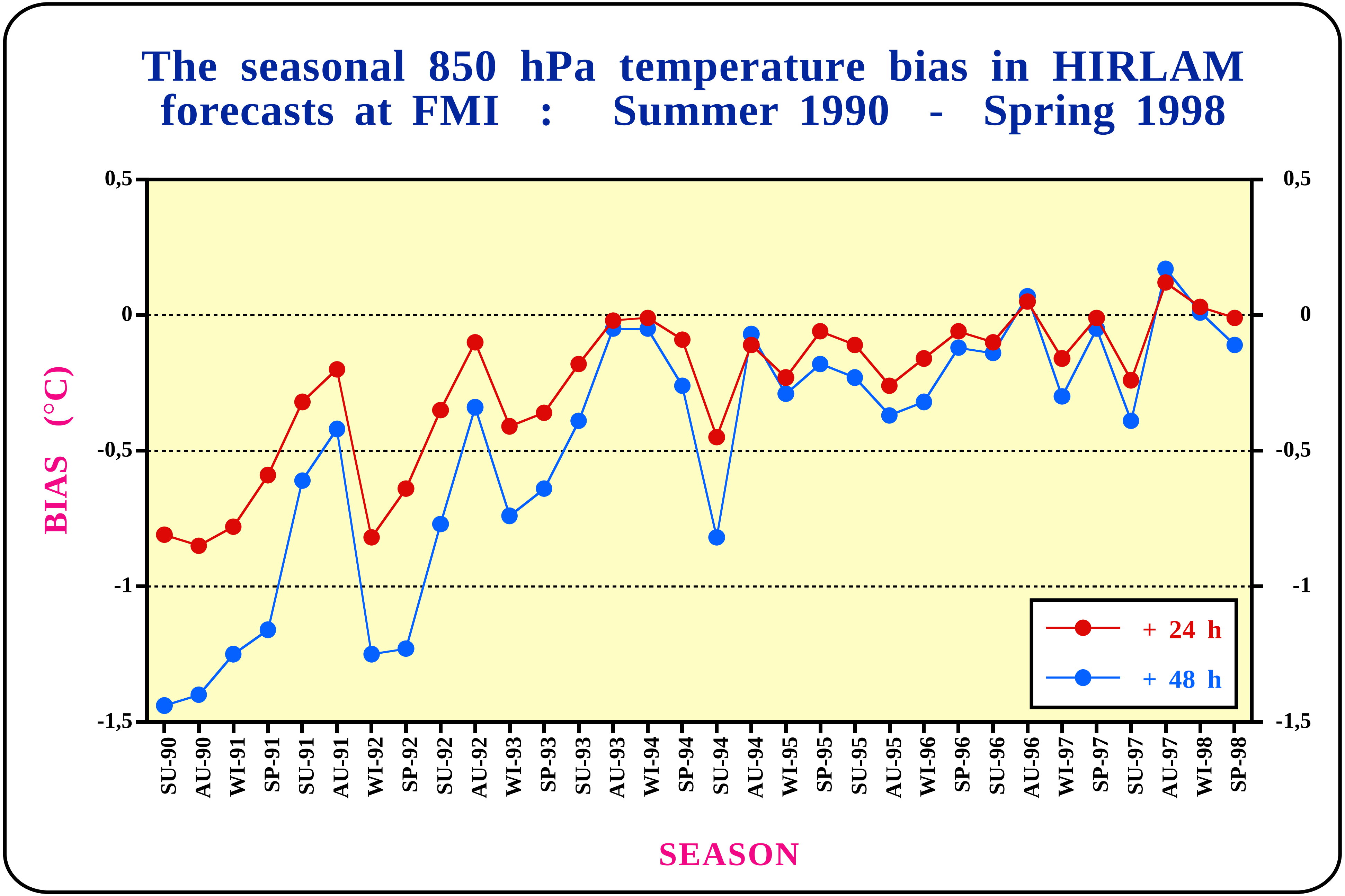



Figure 8: Net radiation at TOA, Dec86-Jan87 [Fortelius and Siljamo(1996)].


The seasonal 850 hPa temperature bias in HIRLAM forecasts at FMI : Summer 1990 - Spring 1998
BIAS (°C)
SEASON
0,5
0
-0,5
-1
-1,5
SU-90
AU-90
WI-91
SP-91
SU-91
AU-91
WI-92
SP-92
SU-92
AU-92
WI-93
SP-93
SU-93
AU-93
WI-94
SP-94
SU-94
AU-94
WI-95
SP-95
SU-95
AU-95
WI-96
SP-96
SU-96
AU-96
WI-97
SP-97
SU-97
AU-97
WI-98
SP-98
+ 24 h
+ 48 h

## CONCLUSIONS

**Fast and simple, physically based radiation scheme gives results sufficiently accurate for a short-range limited area model.**

**The main result of a radiation scheme: surface radiation fluxes $\rightarrow$ surface energy balance $\rightarrow$ $T_{2m}$.**

**Largest variations in radiation fluxes are due to changes in cloudiness $\rightarrow$ importance of consistent cloud and radiation parametrizations.**

# References

[Sass et al.(1994)] Sass, B. H., L. Rontu and P. Räisänen, 1994: *HIRLAM-2 Radiation Scheme: Documentation and Tests*. **Technical Report No. 16**, The HIRLAM 3 Project, c/o SMHI, S-601 76 Norrköping, Sweden.

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Short summary of the HIRLAM radiation scheme
written by Hannu Savijärvi (from Wyser et al. (1999))
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## Radiation scheme

The HIRLAM radiation scheme is documented in Sass et al. (1994). It is based on Savijärvi (1990); only a brief overview is given here. The scheme was designed to be fast, so only one vertical loop is allowed in both the solar (short-wave, SW) and the thermal (long-wave, LW) part. The SW clear-air global flux is obtained by reducing the top-of-the-atmosphere (TOA) horizontal flux by broadband average ozone absorption (350 DU), water vapour absorption (depending on the scaled precipitable water content $u$), and Rayleigh scattering in the column. Average aerosol, $CO_2$, and $O_2$ effects are also included. In cloudy air the SW flux is reduced by the total cloud transmissivity $\hat{T}$, also taking into account multiple reflections between cloudbase and the surface. In a partly cloudy column the clear-sky and cloudy sky results are linearly combined.

The cloud SW transmissivity and absorptivity functions are fits to detailed multiple scattering scheme calculations (Slingo (1989), Stephens (1978), Liou and Wittman (1979), Ramaswamy and Freidenreich (1992)), for stratus-type clouds with an effective drop radius of about $10\,\mu$m. The functions depend on the solar zenith angle $\theta$ and the modified cloud condensate amount $\hat{M}$ (in $\mathrm{g\,m^{-2}}$), which is the vertical integral above the level under consideration of $CCC$ multiplied by the relation of the cloud cover $C$ to the maximum cloud cover of the whole column $C_{max}$,

$$\hat{M}(z) = C_{max}^{-1} \int_z^{\mathrm{TOA}} CCC(z')C(z')\,dz'. \tag{1}$$

The absorptivity is

$$\hat{A} = b_{10}(b_{11} + \cos\theta)\log(1 + b_{12}\hat{M}) \tag{2}$$

with the parameters $b_{10} = 0.013$, $b_{11} = 1$, and $b_{12} = 0.1\,\mathrm{m^2\,g^{-1}}$. The transmissivity is given by

$$\hat{T} = \hat{T}_1 / \left(\hat{T}_1 + \hat{M}\right) \tag{3}$$

where

$$\hat{T}_1 = b_{13}(b_{14} + \cos\theta) \tag{4}$$

with the parameters $b_{13} = 40\,\mathrm{gm^{-2}}$ and $b_{14} = 0.5$.

Clear-air solar heating due to water vapour absorption, $a(u)$, is obtained by vertical flux convergence, fitting $\partial a/\partial u$ from the line-by-line $a(u)$ curves of Chou (1986). In and below clouds the clear-air values are reduced by the cloud transmittance $\hat{T}$. In clouds there is also extra heating due to cloud drop absorption, represented by the flux convergence of the absorptivity, $\partial\hat{A}/\partial p$.

Ice clouds are not treated separately in the SW scheme. All clouds are considered to consist of liquid water droplets.

The LW part uses a broadband emissivity scheme in a local isothermal approximation. The water vapour line emissivity is a cubic function of $\log u$; continuum, $CO_2$, and $O_3$ effects are added as extra terms. There can be clouds both above and below the layer in question. Cloud effective emissivity is $C(1-\exp(-k_a m))$, where $C$ is the fractional cloud cover, $m = CCC\Delta z$ is the cloud condensate amount (in $\mathrm{g m^{-2}}$) of the layer with a thickness $\Delta z$, and the cloud mass absorption coefficient $k_a$ decreases linearly with the vertical hybrid $\eta$ coordinate, so as to give smaller values for ice clouds as is observed. Near the surface $k_a$ is $0.20\,\mathrm{m^2\,g^{-1}}$, and near the tropopause $0.05\,\mathrm{m^2\,g^{-1}}$.

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Liou, K. N. and G. D. Wittman, 1979: Parameterization of the radiative properties of clouds. *J. Atmos. Sci.*, **36**, 1261–1273.

Ramaswamy, V. and S. M. Freidenreich, 1992: A study of broadband parametrizations of the solar radiative interactions with water vapor and water drops. *J. Geophys. Res.*, **97**(D11), 11487–11512.

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