Atmosphere-surface coupling and radiation in LMDZ

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Il existe une note interne sur le sujet

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Atmosphere-surface interactions

The **atmosphere and the surface are coupled** through *turbulent diffusion* (in boundary layer) and *radiation* (SW and LW). Currently, there are no direct influence of the surface to other parametrizations.

The surface impacts the atmosphere via the orography (factors constant with time)

The surface “receive” precipitation from the atmosphere (no direct feedback).

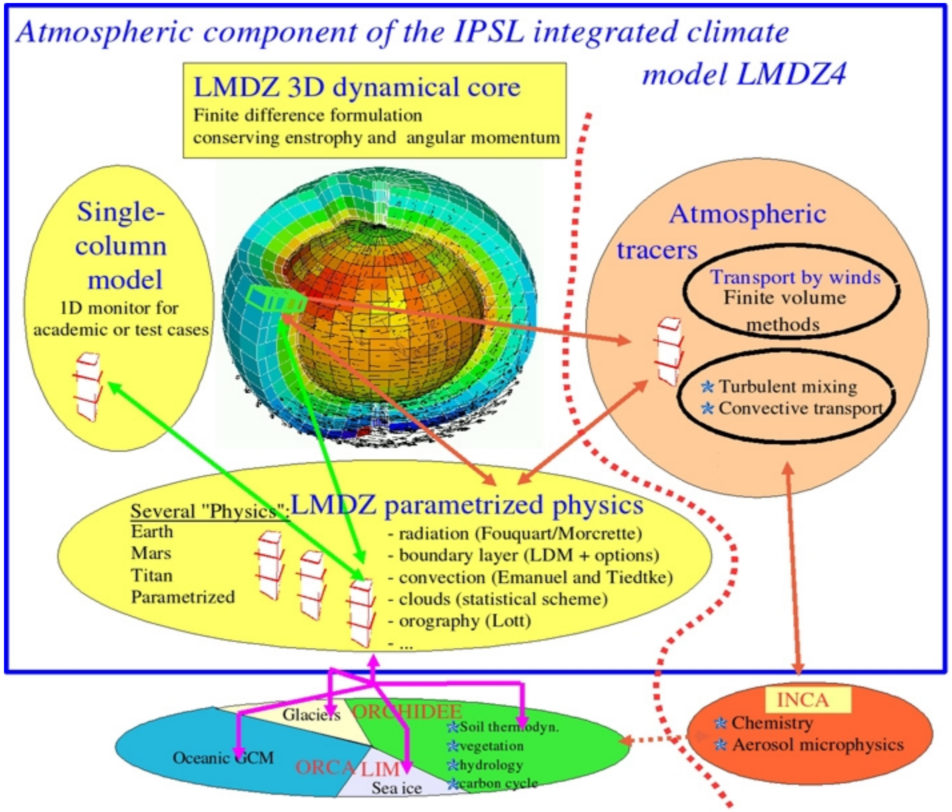
In LMDZ:

Each surface grid may be decomposed in a maximum of 4 sub-grids of different types:
land (_ter), continental ice (_lic), open ocean (_oce), sea-ice (_sic)

Radiation depends only on mean surface properties

Turbulent diffusion depends on local sub-grid property

No influence of sub-surface properties to any other parameterization.



Derivation of local sub-surface **net solar radiation** from grid average net solar radiation

The grid average net flux Ψ_s at surface has been computed for each grid point by the radiative code.

We want (1) to conserve energy and (2) to take into account the value of the local albedo α_i of the sub-surface.

We compute the downward SW radiation as $$F_{\downarrow}^{s} = \frac{\Psi_s}{(1-\alpha)}$$

with the mean albedo $$\alpha = \sum_i \omega_i \alpha_i$$

For each sub-surface, the absorbed solar radiation reads: $$\psi_i^s = (1-\alpha_i) F_{\downarrow}^{s}$$

$$\psi_i^s = \frac{(1-\alpha_i)}{(1-\alpha)} \bar{\Psi}^s$$

One may verified that this procedure ensure energy conservation, i.e. $$\sum_i \omega_i \psi_i^s = \Psi_s$$

Derivation of local sub-surface **net longwave radiation** from grid average net longwave radiation

The net longwave (LW) radiation $\bar{\Psi}^L$ has been computed by the radiative code for each grid cell. How to split it depending on the sub-surfaces local properties and ensuring energy conservation?

If the downward longwave flux $F_\downarrow$ is uniform within each grid, the net LW flux for a sub-surface i may be written as:

$$\psi_i^L(T_i) = \epsilon_i \left(F_\downarrow - \sigma T_i^4\right) \tag{1}$$

where T_i is the surface temperature of sub-surface i and ϵ_i its emissivity. A linearization around the mean temperature $\bar{T}$ gives:

$$\psi_i^L(T_i) \approx \epsilon_i \left(F_\downarrow - \sigma \bar{T}^4\right) - 4\epsilon_i \sigma \bar{T}^3 (T_i - \bar{T}) \tag{2}$$

To conserve the energy, the following relationship must be true:

$$\sum_i \omega_i \psi_i^L = \bar{\Psi}^L \tag{3}$$

Using Eq. 2 gives

$$\sum_i \omega_i \psi_i^L = \bar{\epsilon} \left(F_\downarrow - \sigma \bar{T}^4\right) - 4\sigma \bar{T}^3 \sum_i \omega_i \epsilon_i \left(T_i - \bar{T}\right) \tag{4}$$

where $\bar{\epsilon} = \sum_i \omega_i \epsilon_i$ is the mean emissivity.

Derivation of local sub-surface **net longwave radiation** from grid average net longwave radiation

$$\sum_i \omega_i \psi_i^L = \bar{\epsilon}\left(F_\downarrow - \sigma \bar{T}^4\right) - 4\sigma\bar{T}^3 \sum_i \omega_i \epsilon_i \left(T_i - \bar{T}\right) \tag{4}$$

where $\bar{\epsilon} = \sum_i \omega_i \epsilon_i$ is the mean emissivity. The second term on the right hand side is zero if

$$\bar{T} = \frac{\sum_i \omega_i \epsilon_i T_i}{\bar{\epsilon}} \tag{5}$$

To ensure energy conservation, we need in addition to verify:

$$\bar{\Psi}^L = \bar{\epsilon}\left(F_\downarrow - \sigma \bar{T}^4\right) \tag{6}$$

Which is consistent with the definition of the net LW flux at the surface. We rewrite now Eq. 2 as:

$$\psi_i^L(T_i) \approx \frac{\epsilon_i}{\bar{\epsilon}} \bar{\Psi}^L - 4\epsilon_i \sigma \bar{T}^3 (T_i - \bar{T}) \tag{7}$$

Due to radiative code limitation, in LMDZ, we always must have $\varepsilon_i = 1$

Turbulent diffusion

The change of a variable X with time due to vertical diffusion is:

$$\rho \partial_t X = -\partial_z \phi \tag{8}$$

where ρ is the volumic mass ($kg.m^{-3}$). Variable X can be the specific humidity, moist static energy, momentum, tracer.... ϕ is the flux of X and is defined as:

$$\phi = -\rho k_z \partial_z X \tag{9}$$

with k_z is the diffusion coefficient ($m^2.s^{-1}$).

Space discretization. We consider n layers from $l = 1$ (surface) to $l = n$ (top of atmosphere, TOA) and $n+1$ interfaces from $l = 1$ (surface) to $l = n+1$ (TOA). The space discretization of above equations gives

$$m_l \partial_t X_l = \phi_l - \phi_{l+1} \tag{10}$$

$$\phi_l = K_l (X_{l-1} - X_l) \tag{11}$$

with X_l average value of X for layer l, m_l mass per unit surface ($kg.m^{-2}$) of layer l, ϕ_l flux at interface l and

$$K_l = -\frac{k_z \rho^2 g}{P_l - P_{l-1}} \tag{12}$$

with P_l pressure at interface l.

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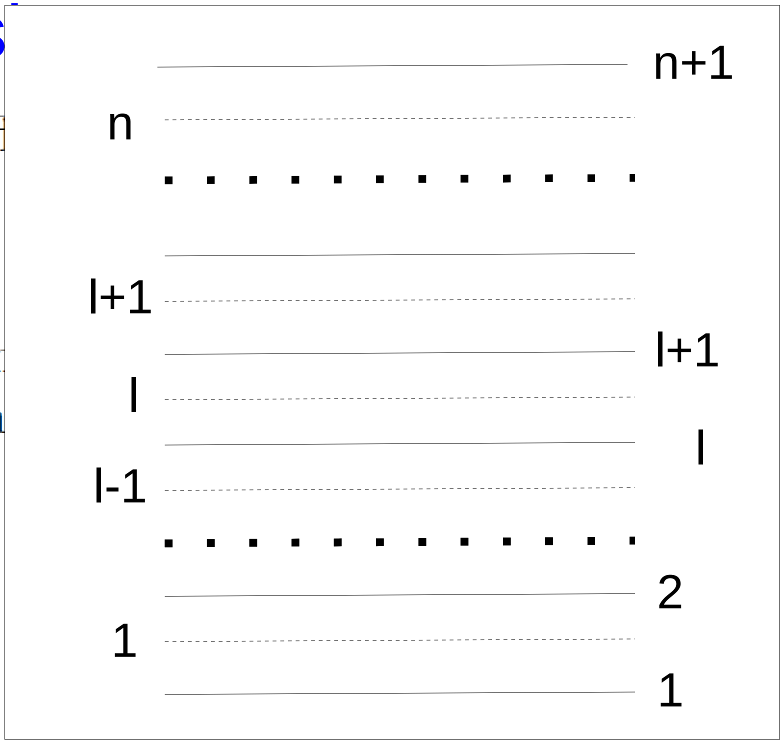

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Turbulent diffusion

$$m_l \partial_t X_l = \phi_l - \phi_{l+1}$$
$$\phi_l = K_l (X_{l-1} - X_l)$$

Time discretization. We use an implicit scheme:

$$m_l \frac{X_l(t+\delta t) - X_l(t)}{\delta t} = \phi_l(t+\delta t) - \phi_{l+1}(t+\delta t) \quad (13)$$

$$m_l \frac{X_l - X_l^0}{\delta t} = \phi_l - \phi_{l+1} \quad (14)$$
$$= K_{l+1}(X_{l+1} - X_l) - K_l(X_l - X_{l-1}) \quad (15)$$

with the following notations: $X_l = X_l(t+\delta t)$ and $X_l^0 = X_l(t)$. This equqations may be written as:

$$\left(\frac{m_l}{\delta t} + K_{l+1} + K_l\right) X_l = \frac{m_l}{\delta t} X_l^0 + K_{l+1} X_{l+1} + K_l X_{l-1} \quad (16)$$

Tridiagonal system that can be solved for vector X

Solving the tridiagonal system

$$\left(\frac{m_l}{\delta t} + K_{l+1} + K_l\right) X_l = \frac{m_l}{\delta t} X_l^0 + K_{l+1} X_{l+1} + K_l X_{l-1}$$

which may be written as:

$$\left(\delta P_l + R_{l+1}^X + R_l^X\right) X_l = \delta P_l \; X_l^0 + R_{l+1}^X \; X_{l+1} + R_l^X \; X_{l-1} \quad (2 \leq l < n)$$

$$\text{with } R_l^X = g \delta t K_l$$

At the top

$$\left(\delta P_n + R_n^X\right) X_n = \delta P_n \; X_n^0 + R_n^X \; X_{n-1}$$

At the bottom

$$\left(\delta P_1 + R_1^X\right) X_1 = \delta P_1 \; X_1^0 + R_2^X \; X_2 - g \delta t F_1^X$$

Solving the tridiagonal system

$$\begin{aligned}\left(\delta P_n + R_n^X\right) X_n &= \delta P_n\ X_n^0 + R_n^X\ X_{n-1} \\ \left(\delta P_l + R_{l+1}^X + R_l^X\right) X_l &= \delta P_l\ X_l^0 + R_{l+1}^X\ X_{l+1} + R_l^X\ X_{l-1} \quad (2 \leq l < n)\end{aligned}$$

Starting from top, one can obtained by reccurence:

$$\boxed{X_l = C_l^X + D_l^X X_{l-1}} \qquad (2 \leq l \leq n)$$

with

$$C_n^X = \frac{X_n^0 \delta P_n}{\delta P_n + R_n^X}$$

$$D_n^X = \frac{R_n^X}{\delta P_n + R_n^X}$$

for $(2 \leq l < n)$

$$C_l^X = \frac{X_l^0 \delta P_l + R_{l+1}^X C_{l+1}^X}{\delta P_l + R_l^X + R_{l+1}^X (1 - D_{l+1}^X)}$$

$$D_l^X = \frac{R_l^X}{\delta P_l + R_l^X + R_{l+1}^X (1 - D_{l+1}^X)}$$

Solving the tridiagonal system

At the bottom

$$X_2 = C_2^X + D_2^X X_1$$

$$\left(\delta P_1 + R_1^X\right) X_1 = \delta P_1 \; X_1^0 + R_2^X \; X_2 - g\delta t F_1^X$$

using Eq. 33 to replace X_2 in the equation above:

$$X_1 = A_1^X + B_1^X . F_1^X . \delta t$$

with

$$A_1^X = \frac{X_1^0 \delta P_1 + R_2^X C_2^X}{\delta P_1 + R_2^X (1 - D_2^X)}$$

$$B_1^X = \frac{-g}{\delta P_1 + R_2^X (1 - D_2^X)}$$

If F_1 is known, then X_1 and all other X_l are knwon, and also the flux Φ_l

Coupling with the surface

Equation for the variables of the first layer

$$X_1 = A_1^X + B_1^X . F_1^X . \delta t$$

Sensitivity of X_1 to the flux at surface F_1

Value if the flux F_1=0

X: temperature T, humidity q, velocity Vx and Vy

F^X: Flux of heat, flux of water mass or flux of momentum

Typical expression of the flux with the surface

$F_1 = K_1 (T_1 - T_s)$

Each surface model has to compute the flux F_1 using variables X_1, A_1 and B_1

In LMDZ, the turbulent flux are computed separately over each sub-surface type

Call tree

In subroutine PHYSIQ

loop over time steps

CALL change_srf_frac : Update fraction of the sub-surfaces (pctsrf)

....

CALL pbl_surface Main subroutine for the interface with surface

- Calculate net radiation at sub-surface
- *Loop over the sub-surfaces nsrf*
  - Compress variables (Consider only one surface type and only the points for which the fraction for this sub-surface in not zero)
  - CALL clcdrag: coefficients for turbulent diffusion at surface (cdragh and cdragm)
  - CALL coef_diff_turb: coef. turbulent dif. in the atmosphere (ycoefm et ycoefm.)
  - CALL climb_hq_down downhill for henthalpie H and humidity Q
  - CALL climb_wind_down downhill for wing (U and V)
  - CALL surface models for the various surface types: **surf_land, surf_landice, surf_ocean or surf_seaice**. **Each surface model computes:**
    - evaporation, latent heat flux, sensible heat flux
    - surface temperature, albedo
  - CALL climb_hq_up : compute new values of henthalpie H and humidity Q
  - CALL climb_wind_up : compute new values of wind (U and V)
  - Uncompress variables : (some variables are per unit of sub-surface fraction, some are per unit of grid surface fraction)
  - Cumulate in global variables after weighting by sub-surface fractions
  - Surface diagnostics : (T2m, Q2m, wind at 10m...)
- *End Loop over the sub-surfaces*
- Calculate the mean values over all sub-surfaces for some variables

End pbl-surface

Radiation

Two radiative codes, from ECMWF:

1) Old (very)
• SW, 2 bands (Fouquart and Bonnel, 1980)
• LW, 6 bands (Mocrette et al., 1986). Transmission functions (not exponentiel)

2) New (not too old)
• SW: 2, 4 and 6 bands (Fouquart and Bonnel, 1980)
• LW: 16 bands (RRTM, Mlawer at al., 1997). Correlated-k methode. Wide band radiative transfer can be computed like monochromatic transfer (exponentiel)

3) ...

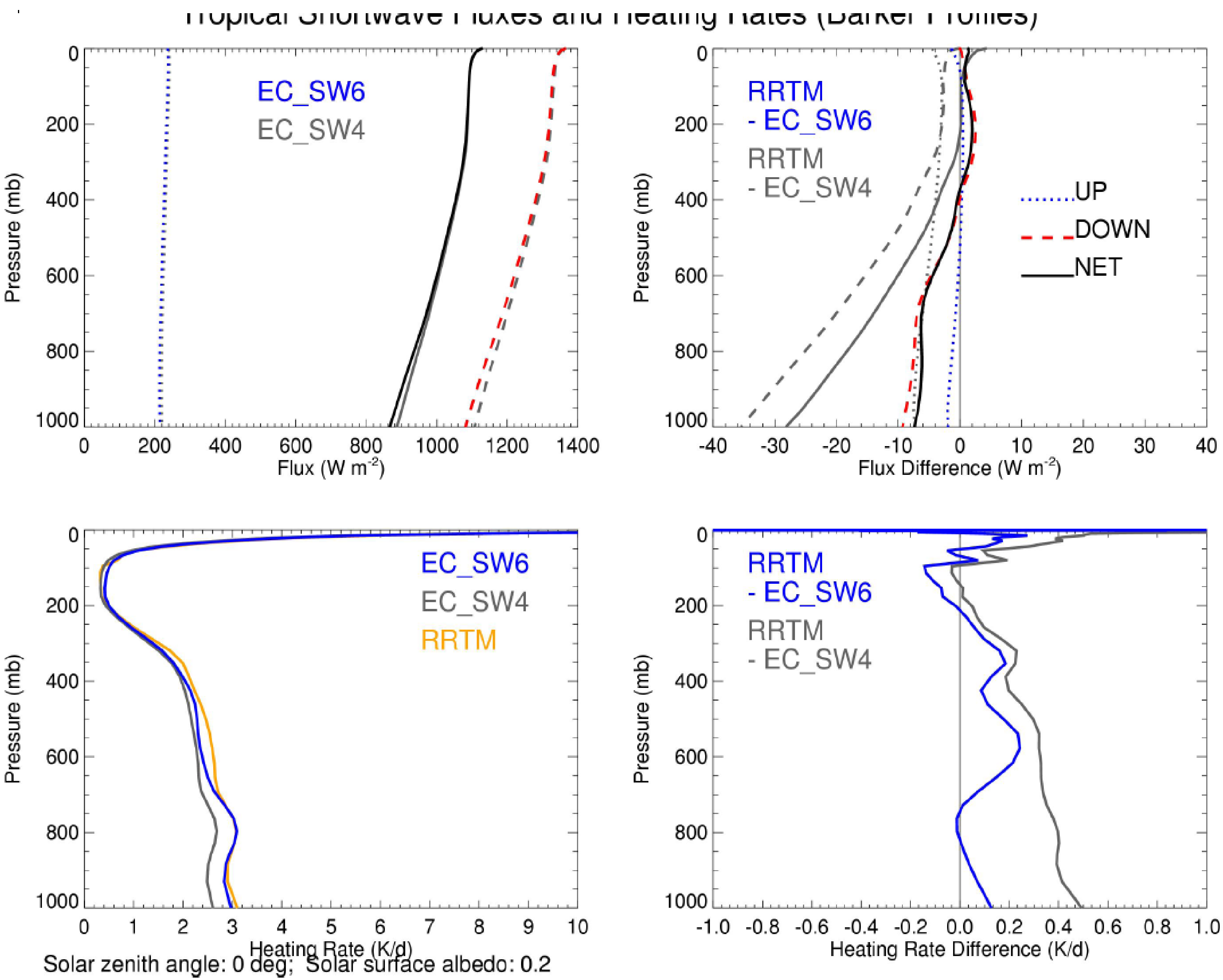
- 6 spectral intervals from 0.185 to 4 μm
- Based on a line-by-line model of the transmission functions
  - LbL based on STRANSAC (Scott, 1974, Dubuisson et al., 1996)
  - modified to account for HITRAN 2000
  - H_2O, CO_2, O_3, O_2, CH_4, CO, N_2O
  - resolution 0.01 cm^{-1} from 2000 to 20000 cm^{-1}, then resolution of the O3 continuum, i.e. 5 to 10 cm^{-1}
- UV_{CBA} in 2 intervals, 0.185-0.25-0.4 μm, visible in 1 interval, 0.4-0.69 μm

4 spectral intervals from 0.25 to 4 μm

Based on statistical models of the transmission functions

UV_{BA} and visible in one interval from 0.25 to 0.69 μm

The 6-interval SW radiation scheme - 3



The new SW scheme SW6 is compared to the old SW4, and to results obtained from a different scheme linked to a different line-by-line model, RRTM

Differences in tropospheric SW heating rates:

A small impact is seen in the troposphere, related to a water vapour absorption including both a p- and e-type absorption

ECMWF

The ECMWF LW radiation schemes: RRTM_LW vs. M91/G00

Table 1: Characteristics of the longwave radiation schemes

	RRTM	M91/G00
Solution of Radiative Transfer Equation	two-stream method	spectral emissivity method
Number of spectral intervals	16	6
Absorbers	H_2O, CO_2, O_3, CH_4, N_2O, CFC11, CFC12, aerosols	H_2O, CO_2, O_3, CH_4, N_2O, CFC11, CFC12, aerosols
Spectroscopic database	HITRAN 1996	HITRAN 1992
Absorption coefficients	from LBLRTM line-by-line model	fits on statistical models of transmission
Cloud handling	true cloud fraction	effective cloud fraction CF*ε
Cloud optical properties: method	16-band spectral emissivity	whole spectrum emissivity
Data Ice Clouds Water Clouds	Ebert & Curry '92, Fu et al. '98 Smith & Shi '92, Savijarvi & Raisanen'97	Ebert & Curry, 92 Smith & Shi '92
Cloud overlap assumption	maximum-random	maximum-random (maximum & random also possible)
Reference	Mlawer et al., 1997	Morcrette et al., 1986 Morcrette, 1991 Gregory et al., 1998

M91/G00

Morcrette, 1991, JGR, 96D, 9121-9132
Gregory et al., 2000, QJRMS, 126A, 1685-1710.

- Band-emissivity type of scheme, i.e., solves for a $(N+1)^2$ matrix of transmission functions

$$F_+(p) = [B_k(T_{surf}) - B_k(T_{0+})]t_{Bk}(p_{surf}, p) + B_k(T(p)) + \int_{p'=p_{surf}}^{p} t_{dBk}(p, p', r)\, dB_k$$

$$F_-(p) = [B_k(T_{top}) - B_k(T_\infty)]t_{Bk}(p, 0) - B_k(T(p)) - \int_{p'=p}^{0} t_{dBk}(p, p', r)\, dB_k$$

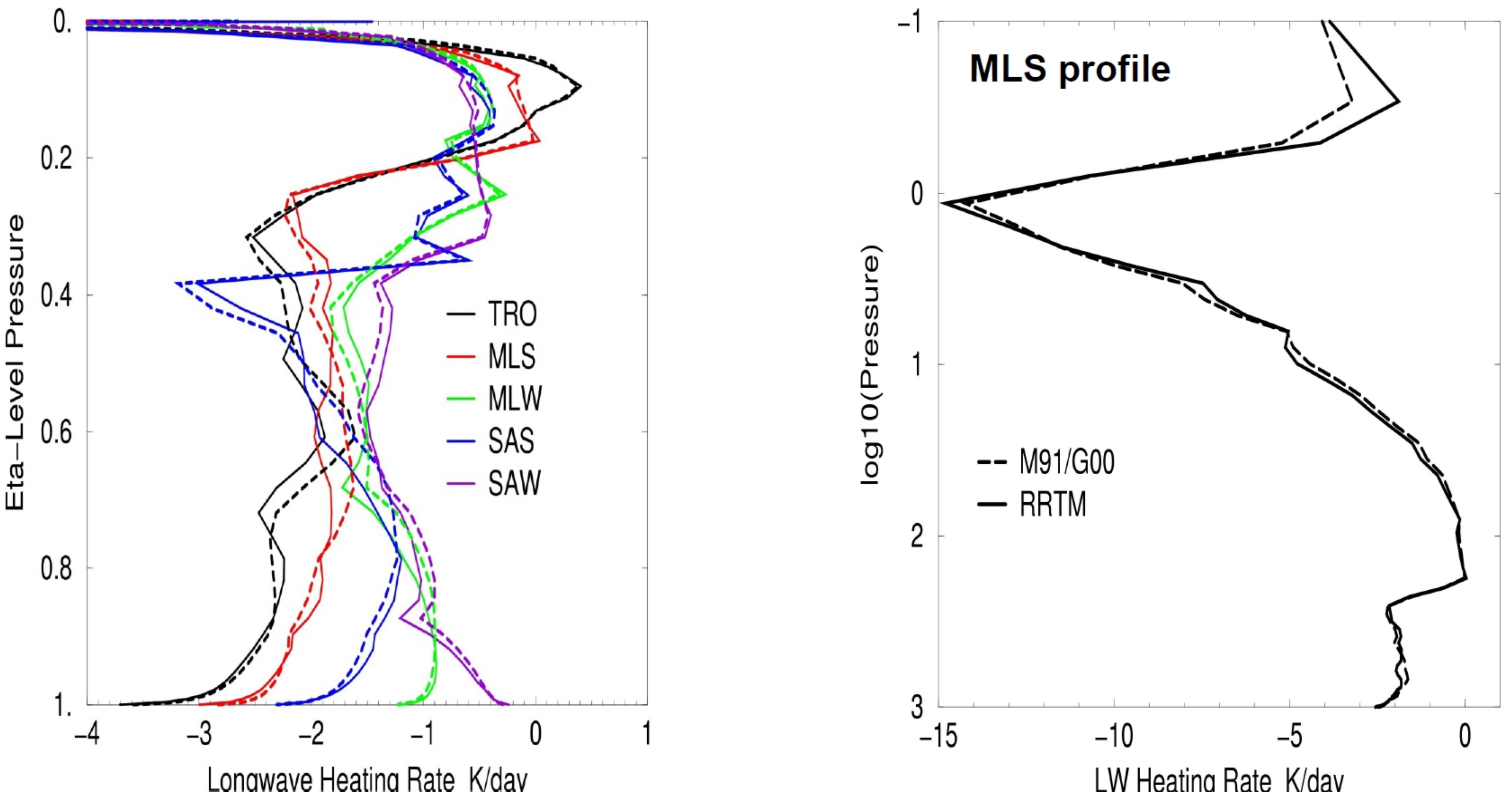
- Six spectral intervals
  - 0-350 + 1450-1680 cm^{-1}
  - 500-800 cm^{-1}
  - 800-970 cm^{-1}
  - 970-1110 cm^{-1}
  - 350-500 cm^{-1}
  - 1250-1450 + 1880-2820 cm^{-1}
- mixed vertical quadrature:
  - 2-point Gaussian for layers adjacent to level of computation
  - trapezoidal rule for distant layers

RRTM: spectral distribution

Table 2.3 *Spectral distribution of the absorption by atmospheric gases in* $RRTM_{LW}$. *Note:* CCl_4 *and CFC22* ($CHClF_2$) *are presently not accounted for in the ECMWF model.*

Wavelength (um)	Spectral intervals cm^{-1}	Number of g-points	Gases included	
			Troposphere	Stratosphere
	10–250	8	H_2O	H_2O
	250–500	14	H_2O	H_2O
16-25	500–630	16	H_2O, CO_2	H_2O, CO_2
	630–700	14	H_2O, CO_2	O_3, CO_2
12-14	700–820	16	H_2O, CO_2, CCl_4	O_3, CO_2, CCl_4
	820–980	8	H_2O, CFC11, CFC12	CFC11, CFC12
9.2-10.2	980–1080	12	H_2O, O_3	O_3
	1080–1180	8	H_2O, CFC12, CFC22	O_3, CFC12, CFC22
	1180–1390	12	H_2O, CH_4	CH_4
	1390–1480	6	H_2O	H_2O
	1480–1800	8	H_2O	H_2O
5	1800–2080	8	H_2O	
	2080–2250	4	H_2O, N_2O	
4.3	2250–2380	2	CO_2	CO_2
	2380–2600	2	N_2O, CO_2	
	2600–3000	2	H_2O, CH_4	

RRTM_LW vs. M91/G00:
Impact when operationally introduced in 2000



ECMWF