Recent developments in radiation transfer with impact on the stratosphere of the ECMWF forecast system

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With discussion, comments and help from
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Radiation and stratosphere in the ECMWF model: Outline

- Impact of changes in RT schemes on the ECMWF model stratosphere
  - LW: from M’91 to RRTM
  - SW: from SW4 to SW6
  - Without and with O$_3$/radiation interactions

- Role of the high level cloudiness on the temperature and ozone in lower stratosphere

- Comparisons of T, and ozone profiles with ozonesonde measurements

- Towards an ECMWF operational UV-b diagnostics
Radiation and stratosphere in the ECMWF model:

Control July

Average of p108/t128 20020401 1200 step 2928 Expver edjh (180.0W-180.0E)
"edjh (O3_tracer) July"
"Temperature"

Average of p110/t128 20020401 1200 step 2928 Expver edjh (180.0W-180.0E)
"edjh (O3_tracer) July"
"Zonal wind"

Average of p112/t128 20020401 1200 step 2928 Expver edjh (180.0W-180.0E)
"edjh (O3_tracer) July"
"Vertical velocity"

T_L 159 L60 started 20020401
Averaged over July 2002
Operational cycle 26r1
Prognostic O_3 not interactive with radiation
Radiation with Fortuin-Langematz climatology
SW: 6 spectral intervals
LW: RRTM
Radiation and stratosphere in the ECMWF model:  Control July

T_{L_{159}} L60 started 20020401
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SW: 6 spectral intervals
LW: RRTM
Radiation and stratosphere in the ECMWF model: Control July

SW heating rate

LW heating rate

T_L 159 L60 started 20020401
Averaged over July 2002
Operational cycle 26r1
Prognostic O_3 not interactive with radiation
Radiation with Fortuin-Langematz climatology
SW: 6 spectral intervals
LW: RRTM
## Impact of recent changes in RT schemes on the model high atmosphere

- 27 June 2000 (cy22r3): replacement of the LW 6-band emissivity scheme by the 16-band two-stream scheme of Mlawer et al. (1997)

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<td>H$_2$O, CO$_2$, O$_3$, CH$_4$, N$_2$O, CFC11, CFC12, aerosols</td>
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<td>Absorption coefficients</td>
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<td>Cloud optical properties</td>
<td>16-band spectral emissivity data</td>
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<td>Cloud overlap assumption</td>
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<td>Reference</td>
<td>Mlawer et al., 1997</td>
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<td>Morcrette, 1991; Gregory et al., 2000</td>
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Impact of recent changes in RT schemes on the model high atmosphere

The LW heating rate computed for a mid-latitude summer standard atmosphere by M91/G00 (dash) and RRTM (full) radiation schemes.

Smaller LW cooling above stratopause
Impact of recent changes in RT schemes on the model high atmosphere

- 9 April 2002 (cy25r1): revision of the SW scheme, from 4 to 6 spectral intervals

<table>
<thead>
<tr>
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<td>2: 0.25 - 0.69 - 4.0</td>
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<td>0.69 - 1.19 - 2.38 - 4.0</td>
<td>4: 0.25 - 0.69 - 1.19 - 2.38 - 4.0</td>
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<td>Spectroscopic database</td>
<td>HAWKS 2000</td>
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<td>Absorption coefficients</td>
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<td>Cloud optical properties</td>
<td>σₐ, ω, g in each spectral interval</td>
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<td>Data</td>
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<td>water clouds</td>
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<tr>
<td>Reference</td>
<td>Dubuisson et al., 1996 for LbL</td>
<td>Fouquart &amp; Bonnel, 1980</td>
</tr>
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<td></td>
<td></td>
<td>Morcrette, 1991, 1993</td>
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</tbody>
</table>
Impact of recent changes in RT schemes on the model high atmosphere

Comparison with a line-by-line model of the SW radiation transfer on standard cases shows an excellent agreement on the flux profiles:

Standard tropical atmosphere:

full line = LbL
dash line = SW6

Top of the atmosphere
The SW heating rate computed for a mid-latitude summer standard atmosphere by the four- (dash) and six- (full) interval versions of the SW scheme (for $\mu_0=0.8$)

Larger SW heating at stratopause
## Experimentation

- **Series of 4-month T_159L60 starting 20020401 (OPE)**
  - Results presented as zonal means of T, q, CF, O_3

- **Series of 20-month T_159L60 integrations starting 20000401 (ERA40)**
  - Results presented as time-series of data averaged over the 90°N-60°N, 30°N-30°S, and 60°S-90°S latitude bands.

In all cases, simulations done with radiation interactive with prognostic O3 (RadInt) vs. radiation computed with O3 from monthly mean climatology of Fortuin & Langematz (1994).
Impact of change in LW-RT scheme on the model high atmosphere

July:
Impact of change of LW radiation scheme for climatological O₃ in RT

RRTM - M91/G00
Both simulations with SW6

Temperature difference $\Delta T$ in K

Relative difference in humidity $\Delta q/q$ in %
Impact of change in LW-RT scheme on the model high atmosphere

July:
Impact of change of LW radiation scheme for climatological O₃ in RT

RRTM - M91/G00
Both simulations with SW6

Cloud fraction difference $\Delta CC$ in %

Through a slight reduction in LW cooling in the lower troposphere, RRTM actually destabilizes the tropics, increases convection, moistening the upper troposphere, increasing the uppermost cloudiness.

Through a decreased LW cooling in stratosphere, increase in temperature in upper model layers
Impact of change in SW-RT scheme on the model high atmosphere

July:
Impact of change of SW radiation scheme for climatological O$_3$ in RT

SW6 – SW4
Both simulations with RRTM

Temperature difference $\Delta T$ in K

Relative difference in humidity $\Delta q/q$ in %
Impact of change in SW-RT scheme on the model high atmosphere

Through an increase absorption by stratospheric O$_3$ and tropospheric H$_2$O (due to change in absorption coefficients), increase in temperature over most of the stratosphere, and slight increase in convection leading to slight increase in upper tropospheric humidity.

What does radiation interactive with prognostic O$_3$ add to this?
Impact of interactions between prognostic ozone and radiation

July:
RRTM, SW6

\( O_{3\text{-RadInt}} - O_{3\text{-clim}} \)

Temperature difference \( \Delta T \) in K

Relative difference in humidity \( \Delta q/q \) in %
Impact of interactions between prognostic ozone and radiation

July:
RRTM, SW6

\[ O_{3\text{ RadInt}} - O_{3\text{ clim}} \]

Cloud fraction difference $\Delta CC$ in %

Relative difference $\Delta q_{O3}/q_{O3}$ in %
Impact of interactions between prognostic ozone and radiation

July:
M91/G00, SW4

O$_3$-RadInt – O$_3$-clim

Temperature difference $\Delta T$ in K

Relative difference in humidity $\Delta q/q$ in %
Impact of interactions between prognostic ozone and radiation

**July:**
M91/G00, SW4

O3_RadInt – O3_clim

Cloud fraction difference $\Delta CC$ in %

relative difference $\Delta q_{O3}/q_{O3}$ in %
Comparison between prognostic ozone and Fortuin-Langematz's ozone climatology for July

O3_tracer-FL

O3RadInt-FL

OPE-FL

Initial conditions

TL511L60

TL159L60 started 200204
Impact of interactions between prognostic ozone and radiation

Whatever the radiation schemes, the impact of having RT interactive with prognostic ozone is to cool the area immediately at and above the upper most clouds. This does not appear to be essentially linked to increased high level cloudiness (with colder radiating temperature), but to a much different prognostic O$_3$ amount w.r.t. the Fortuin-Langematz climatology on which radiation has been computed when O$_3$ is a tracer.

Has the representation of high clouds a role to play in this story?
Impact of the representation of high-level cloudiness

* Within the LW and SW radiation schemes, the high cloud optical properties depend on:
  - the ice water content (and ice water path once integrated over the thickness of the layers)
  - a model of cloud optical properties, itself dependent on
  - the effective size of the ice particles

* The operational version of the ECMWF model uses:
  - cloud optical properties from Ebert & Curry (1992)
  - effective particle size $D_e$ diagnosed from temperature between 30 and 60 $\mu$m from Ou and Liou (1995)

* Results are presented with the alternate:
  - cloud optical properties from Fu (1996) in the SW, and Fu et al. (1998) in the LW
  - effective particle size diagnosed from both temperature and ice water content following Sun (2001) making particle size $D_e$ vary between 15 and 150 $\mu$m.
Impact of representation of high cloudiness:
change in De

delta T

delta q/q

Average of p108/t128 20020401 1200 step 2928 Expver edm1 (180.0W-180.0E)
"edm1 (O3_RadInt_DeSun)-edm6 (O3_tracer_DeSun) July"
"Temperature"

Average of p109/t128 20020401 1200 step 2928 Expver edm2 (180.0W-180.0E)
"edm2 (O3_RadInt_FuIceOpt)-edm7 (O3_tracer_FuIceOpt) July"
"Temperature"

Average of p108/t128 20020401 1200 step 2928 Expver edm1 (180.0W-180.0E)
"edm1 (O3_RadInt_DeSun)-edm6 (O3_tracer_DeSun) July"
"Humidity"

Average of p109/t128 20020401 1200 step 2928 Expver edm2 (180.0W-180.0E)
"edm2 (O3_RadInt_FuIceOpt)-edm7 (O3_tracer_FuIceOpt) July"
"Humidity"
Impact of representation of high cloudiness: change in De
change in ice cloud optical properties

Average of p105/t128 20020401 1200 step 2928 Expver edm1 (180.0W-180.0E)
"edm1 (O3_RadInt_DeSun)-edm6 (O3_tracer_DeSun) July"
"Cloud fraction"

Average of p113/t128 20020401 1200 step 2928 Expver edm1 (180.0W-180.0E)
"edm1 (O3_RadInt_DeSun)-edm6 (O3_tracer_DeSun) July"
"Cloud fraction"

Average of p105/t128 20020401 1200 step 2928 Expver edm2 (180.0W-180.0E)
"edm2 (O3_RadInt_FuIceOpt)-edm7 (O3_tracer_FuIceOpt) July"
"Cloud fraction"

Average of p113/t128 20020401 1200 step 2928 Expver edm2 (180.0W-180.0E)
"edm2 (O3_RadInt_FuIceOpt)-edm7 (O3_tracer_FuIceOpt) July"
"Cloud fraction"
Changing the details of the representation of the RT in the ice clouds, which affect the actual Temperature and humidity in the upper tropospheric layers, does not significantly change the Response of the model when going from O3_clim to O3RadInt.

The main contributor is the much different prognostic O$_3$ amount w.r.t. the Fortuin-Langematz climatology on which radiation has been computed when O$_3$ is a tracer.
Impact of O3/radiation interactions on objective scores
Comparisons with ozonesonde measurements

Series of 10-day $T_L^{159L60}$ integrations starting from ERA40 covering dates in January/March 1991, January-March 1992, August-October 1993

- Comparisons presented for T and $O_3$ profiles over ozonesonde stations

- Results presented here for August/October 1993
Objective scores: Anomaly correlation of Z at 100 and 50 hPa

TL 159L60 10-day forecasts started from ERA40 reanalysis: 92 FCs between 19930801 and 19931031

Model cycle 23r4

- **O3_clim**
- **O3RadInt**
Objective scores: Anomaly correlation of Z at 30 and 10 hPa
Objective scores: mean error in T at 100 and 50 hPa

NH 100 hPa

SH 100 hPa

Tropics 100 hPa

NH 50 hPa

SH 50 hPa

Tropics 50 hPa

O3_clim

O3RadInt
Objective scores: mean error in T at 30 and 10 hPa

NH 30 hPa

SH 30 hPa

Tropics 30 hPa

NH 10 hPa

SH 10 hPa

Tropics 10 hPa

O3_clim

O3RadInt
Comparison with $T$ and $O_3$ profiles from ozonesondes:
Ny Alesund: 78.39N 11.88E (Svalbard) August-October 1993

Ny Alesund 19930811 Comparison Obs/Ana/FCs

Ny Alesund 19930811 Comparison Obs/Ana/FCs

Ny Alesund 19930811 Comparison Obs/Ana/FCs

Ny Alesund 19930908 Comparison Obs/Ana/FCs

Ny Alesund 19930908 Comparison Obs/Ana/FCs

Ny Alesund 19930908 Comparison Obs/Ana/FCs

Ny Alesund 19931020 Comparison Obs/Ana/FCs

Ny Alesund 19931020 Comparison Obs/Ana/FCs

Ny Alesund 19931020 Comparison Obs/Ana/FCs
Comparison with T and O₃ profiles from ozonesondes:
Hilo: 19.72N  155.08E (Hawaii)
August-October 1993

Hilo 19930813 Comparison Obs/Ana/FCs

Hilo 19930817 Comparison Obs/Ana/FCs

Hilo 19930914 Comparison Obs/Ana/FCs

- Temperature K
- log₁₀ (Pressure hPa)
- Partial Pressure of O₃ (mPa)

Obs 930813
Ana 930813
DynOnly 930803+10
RadInt 930803+10
Obs 930817
Ana 930817
DynOnly 930807+10
RadInt 930807+10
Obs 930914
Ana 930914
DynOnly 930904+10
RadInt 930904+10
Comparison with T and O$_3$ profiles from ozonesondes:
Niwa-Lauder: 45.04S  169.68E (NZ)  
August-October 1993

Niwa-Lauder 19930811 Comparison Obs/Ana/FCs

Niwa-Lauder 19930912 Comparison Obs/Ana/FCs

Niwa-Lauder 19931014 Comparison Obs/Ana/FCs

Niwa-Lauder 19930811 Comparison Obs/Ana/FCs

Niwa-Lauder 19930912 Comparison Obs/Ana/FCs

Niwa-Lauder 19931014 Comparison Obs/Ana/FCs

Niwa-Lauder 19930811 Comparison Obs/Ana/FCs

Niwa-Lauder 19930912 Comparison Obs/Ana/FCs

Niwa-Lauder 19931014 Comparison Obs/Ana/FCs

Niwa-Lauder 19930811 Comparison Obs/Ana/FCs

Niwa-Lauder 19930912 Comparison Obs/Ana/FCs

Niwa-Lauder 19931014 Comparison Obs/Ana/FCs

Niwa-Lauder 19930811 Comparison Obs/Ana/FCs

Niwa-Lauder 19930912 Comparison Obs/Ana/FCs

Niwa-Lauder 19931014 Comparison Obs/Ana/FCs

Niwa-Lauder 19930811 Comparison Obs/Ana/FCs

Niwa-Lauder 19930912 Comparison Obs/Ana/FCs

Niwa-Lauder 19931014 Comparison Obs/Ana/FCs

Niwa-Lauder 19930811 Comparison Obs/Ana/FCs

Niwa-Lauder 19930912 Comparison Obs/Ana/FCs

Niwa-Lauder 19931014 Comparison Obs/Ana/FCs

Niwa-Lauder 19930811 Comparison Obs/Ana/FCs

Niwa-Lauder 19930912 Comparison Obs/Ana/FCs

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Niwa-Lauder 19931014 Comparison Obs/Ana/FCs

Niwa-Lauder 19930811 Comparison Obs/Ana/FCs

Niwa-Lauder 19930912 Comparison Obs/Ana/FCs

Niwa-Lauder 19931014 Comparison Obs/Ana/FCs

Niwa-Lauder 19930811 Comparison Obs/Ana/FCs

Niwa-Lauder 19930912 Comparison Obs/Ana/FCs

Niwa-Lauder 19931014 Comparison Obs/Ana/FCs

Niwa-Lauder 19930811 Comparison Obs/Ana/FCs

Niwa-Lauder 19930912 Comparison Obs/Ana/FCs

Niwa-Lauder 19931014 Comparison Obs/Ana/FCs
Comparison with T and O₃ profiles from ozonesondes:
South Pole: 89.90S 0E
August-October 1993

South Pole 19930815 Comparison Obs/Ana/FCs

South Pole 19930908 Comparison Obs/Ana/FCs

South Pole 19930916 Comparison Obs/Ana/FCs

South Pole 19931015 Comparison Obs/Ana/FCs

South Pole 19931018 Comparison Obs/Ana/FCs

South Pole 19931018 Comparison Obs/Ana/FCs

South Pole 19930815 Comparison Obs/Ana/FCs

South Pole 19930908 Comparison Obs/Ana/FCs

South Pole 19930916 Comparison Obs/Ana/FCs

South Pole 19931015 Comparison Obs/Ana/FCs

South Pole 19931018 Comparison Obs/Ana/FCs

South Pole 19930815 Comparison Obs/Ana/FCs

South Pole 19930908 Comparison Obs/Ana/FCs

South Pole 19930916 Comparison Obs/Ana/FCs

South Pole 19931015 Comparison Obs/Ana/FCs

South Pole 19931018 Comparison Obs/Ana/FCs

South Pole 19930815 Comparison Obs/Ana/FCs

South Pole 19930908 Comparison Obs/Ana/FCs

South Pole 19930916 Comparison Obs/Ana/FCs

South Pole 19931015 Comparison Obs/Ana/FCs

South Pole 19931018 Comparison Obs/Ana/FCs

South Pole 19930815 Comparison Obs/Ana/FCs

South Pole 19930908 Comparison Obs/Ana/FCs

South Pole 19930916 Comparison Obs/Ana/FCs

South Pole 19931015 Comparison Obs/Ana/FCs

South Pole 19931018 Comparison Obs/Ana/FCs

South Pole 19930815 Comparison Obs/Ana/FCs

South Pole 19930908 Comparison Obs/Ana/FCs

South Pole 19930916 Comparison Obs/Ana/FCs

South Pole 19931015 Comparison Obs/Ana/FCs

South Pole 19931018 Comparison Obs/Ana/FCs

South Pole 19930815 Comparison Obs/Ana/FCs

South Pole 19930908 Comparison Obs/Ana/FCs

South Pole 19930916 Comparison Obs/Ana/FCs

South Pole 19931015 Comparison Obs/Ana/FCs

South Pole 19931018 Comparison Obs/Ana/FCs
Towards the verification of model-produced UV-b

A simple diagnostic of the UV-b radiation from the 0.25-0.44 µm spectral interval of the SW radiation scheme shows a reasonable correlation with observations, mainly through the impact of cloudiness. More systematic comparisons are required to see whether prognostic O3 actually provides a positive impact on this diagnostic quantity.
Conclusions - 1

- The replacement of the LW radiation scheme and revision of the SW radiation scheme both warm the upper stratosphere, with better agreement with climatology.

- When radiation transfer is interactive with the prognostic ozone, anomaly correlation of Z at 100, 50, 30, 10 hPa are slightly improved, but errors in T get larger particularly in the tropics.

- The area above the tropical tropopause, although an area of small radiative heating rate (LW and SW) is very sensitive to a number of parameters:
  - uppermost cloud cover and cloud ice/water content
  - temperature

  When including the O₃/Radiation interactions, the cold temperature bias appearing above the tropical tropopause is linked to a reduced local concentration of O₃ w.r.t. the climatology. As expected, RT acts as a negative feedback but not powerful enough to compensate for the deficiencies in O₃ transport.
Conclusions - 2

- Comparisons of ozonesonde profiles of temperature and ozone with ERA40 and 10-day model profiles show that:
  - There are numerous instances where the 10-day FC profiles are more reasonable than the ERA40 analysed profiles. This is particularly the case for O$_3$ profiles
  - O$_3$/radiation interactions do not greatly modify the results w.r.t. radiation working on O$_3$ climatology

- UV-b radiation will become an operational product once radiation becomes interactive with the prognostic O$_3$. Preliminary comparisons show the small effect of the spatial variations of prognostic O$_3$ w.r.t. O$_3$ from climatology as signal is dominated by cloud variability.