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

Jean-Jacques Morcrette

ECMWF

With discussion, comments and help from

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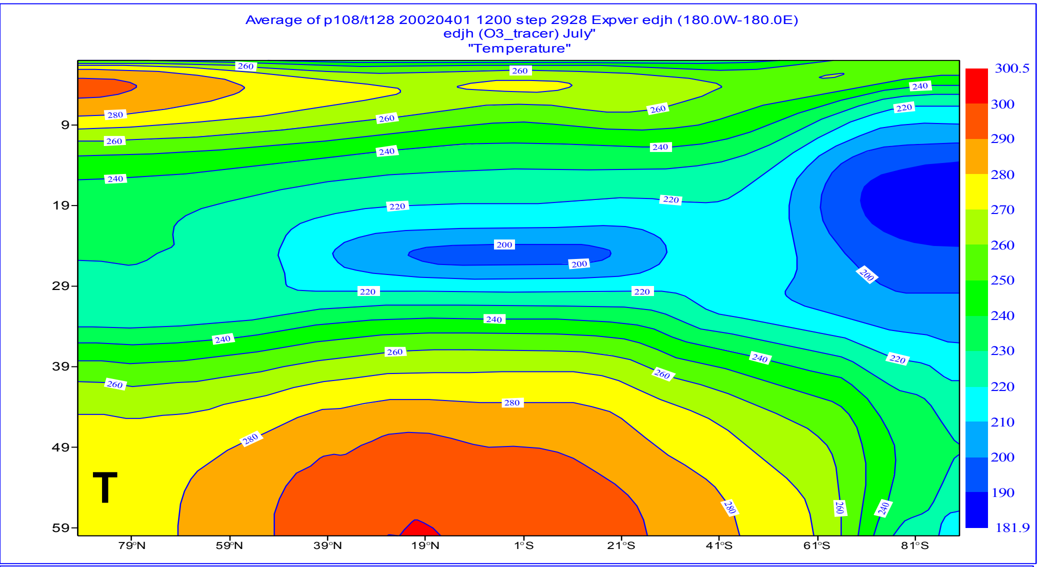
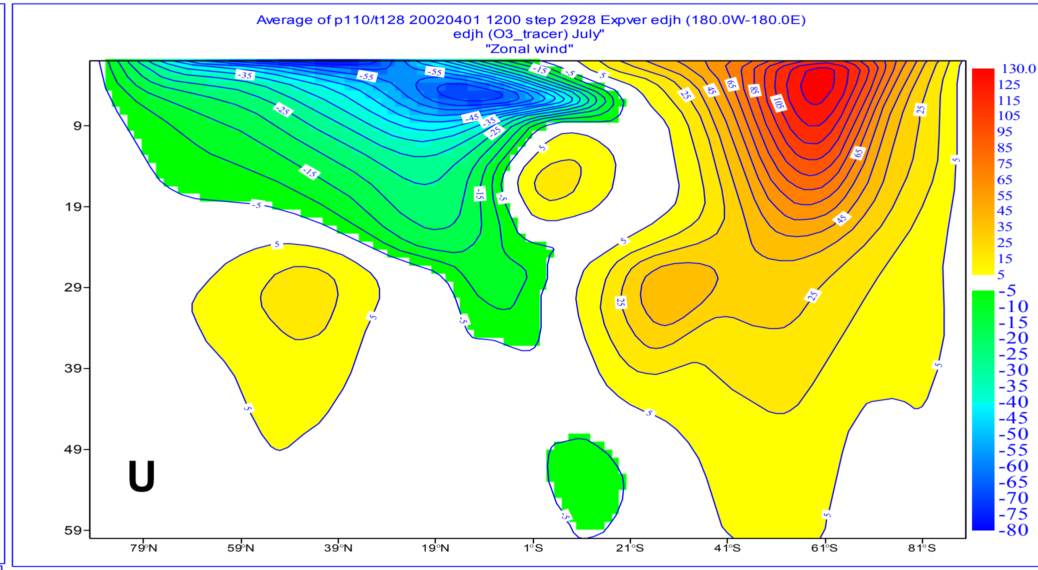
P. Dubuisson, B.Bonnel (LOA, Lille)

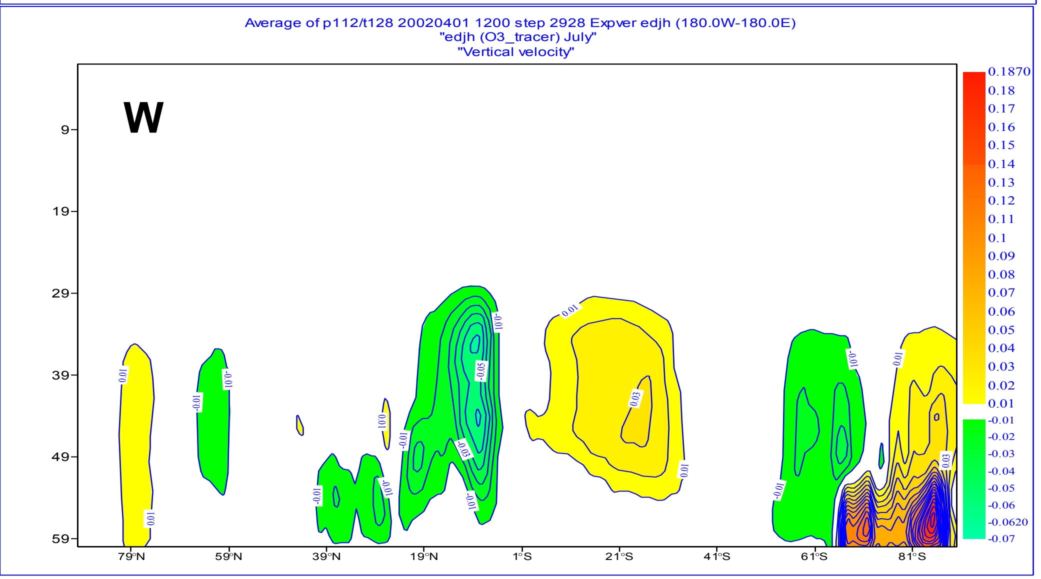
Radiation and stratosphere in the ECMWF model: Outline

- 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







T_L159 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

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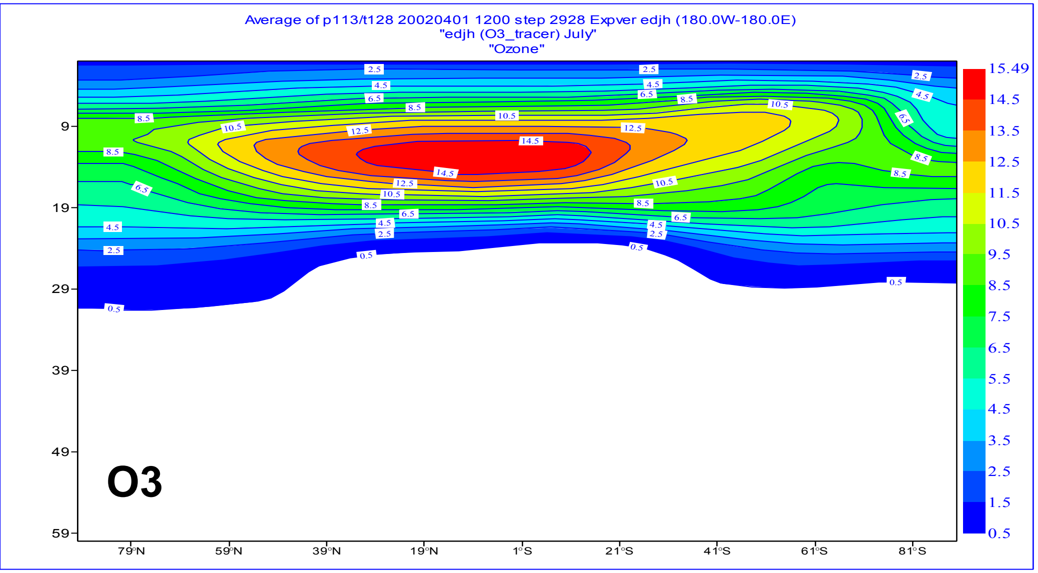
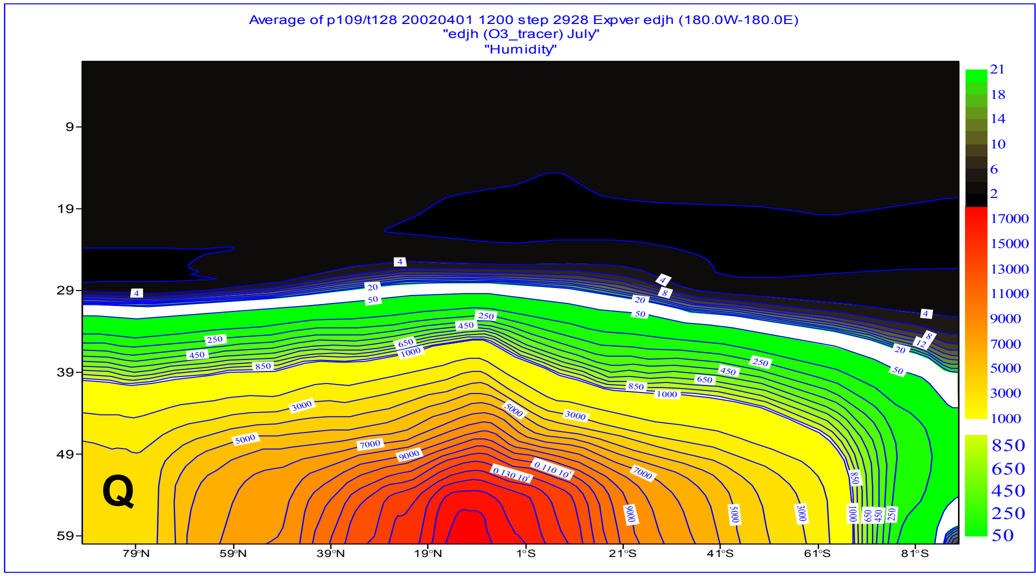
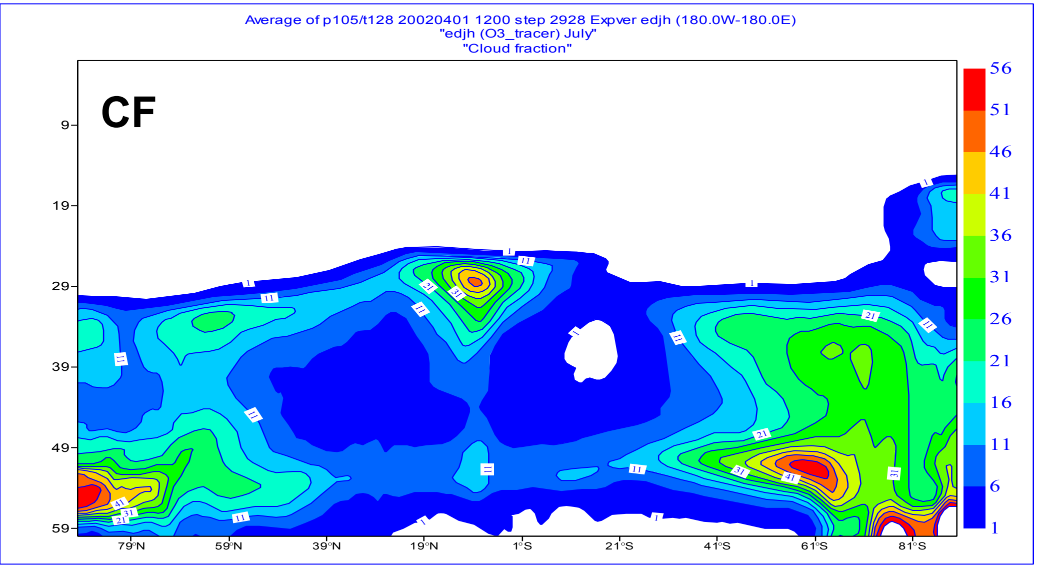
Radiation and stratosphere in the ECMWF model: Control July







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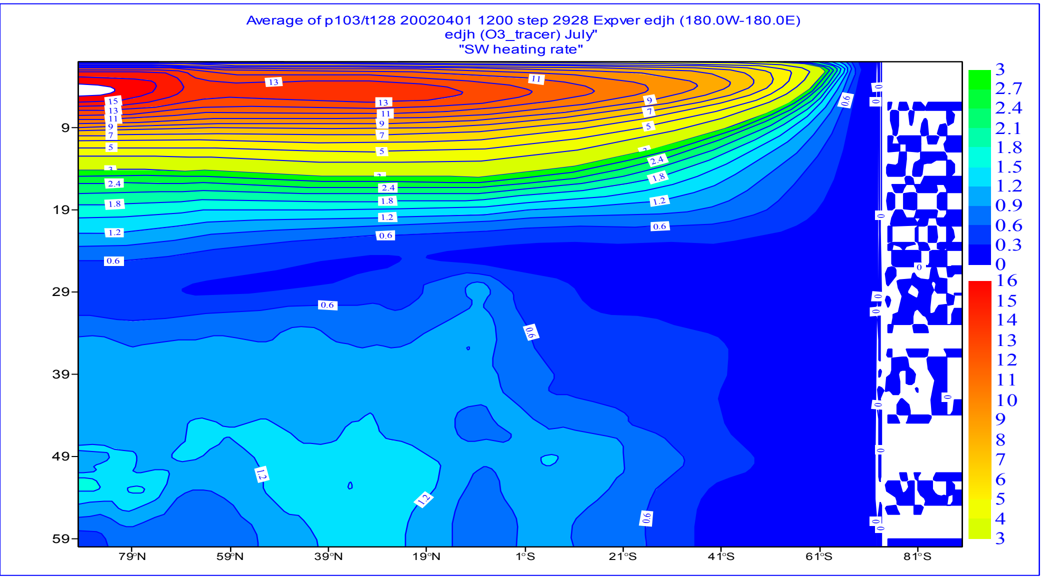

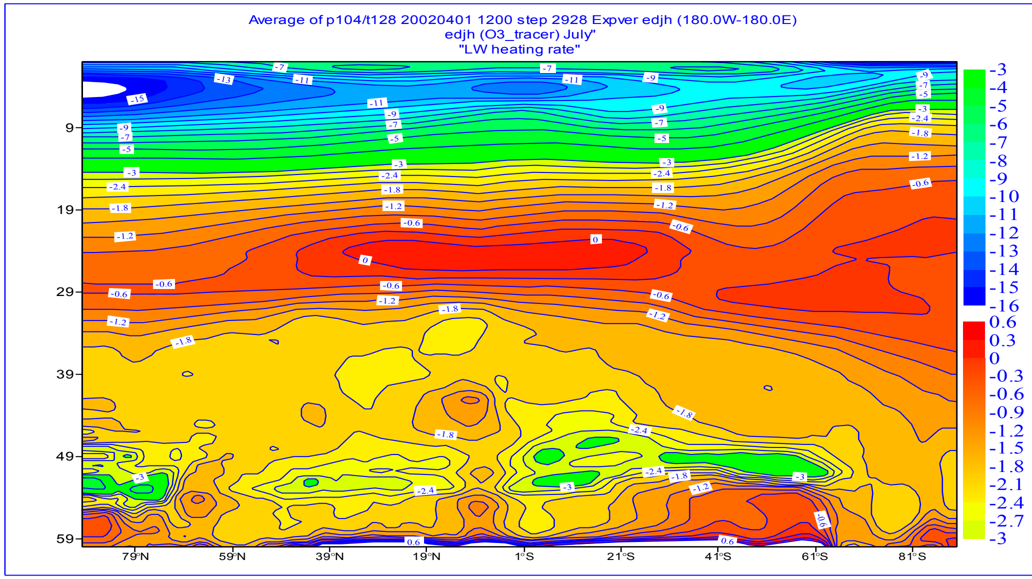

SW heating rate

LW heating rate

T_L159 L60 started 20020401
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SW: 6 spectral intervals
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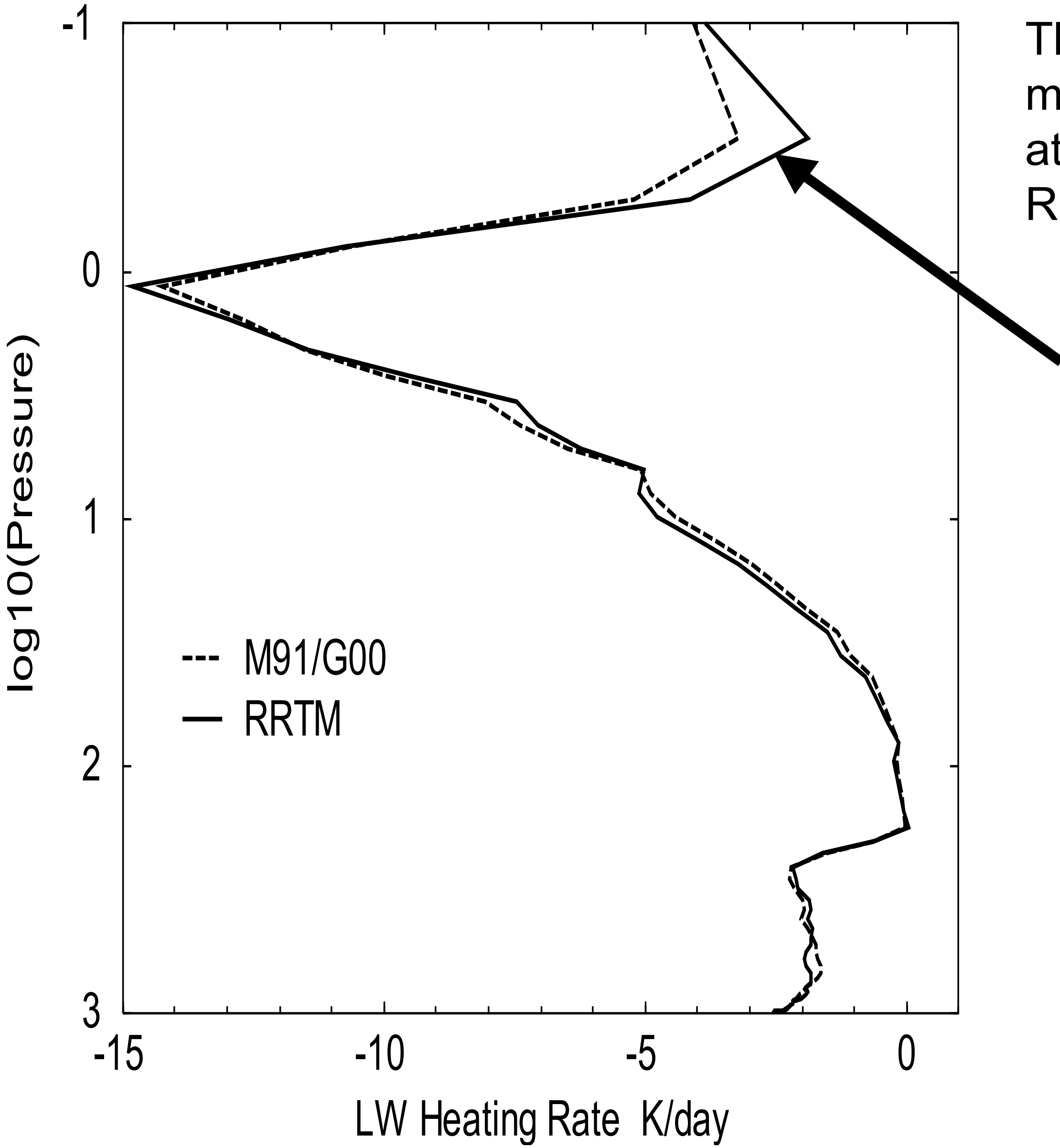
Impact of recent changes in RT schemes on the model high atmosphere

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

	RRTM	M91/G00
Solution of RT equation	two-stream method	spectral emissivity method
Number of spectral intervals	16	6
Absorbers	H_2O, CO_2, O_3, CH_4, N_2O,	H_2O, CO_2, O_3, CH_4, N_2O,
	CFC11, CFC12, aerosols	CFC11, CFC12, aerosols
Spectroscopic database	HITRAN 1996/HAWKS 1998	HITRAN 1992
Absorption coefficients	from LBLRTM line-by-line model	fits on statistical models of transmission
Cloud handling	true cloud fraction	effective cloud fraction $CF^*\varepsilon$
Cloud optical properties		
method	16-band spectral emissivity	whole spectrum emissivity
data		
ice clouds	Ebert & Curry, 1992	Ebert & Curry, 1992
water clouds	Smith & Shi, 1992	Smith & Shi, 1992
Cloud overlap assumption	maximum-random	maximum-random
		(maximum and random also possible)
Reference	Mlawer et al., 1997	Morcrette, 1991; Gregory et al., 2000

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

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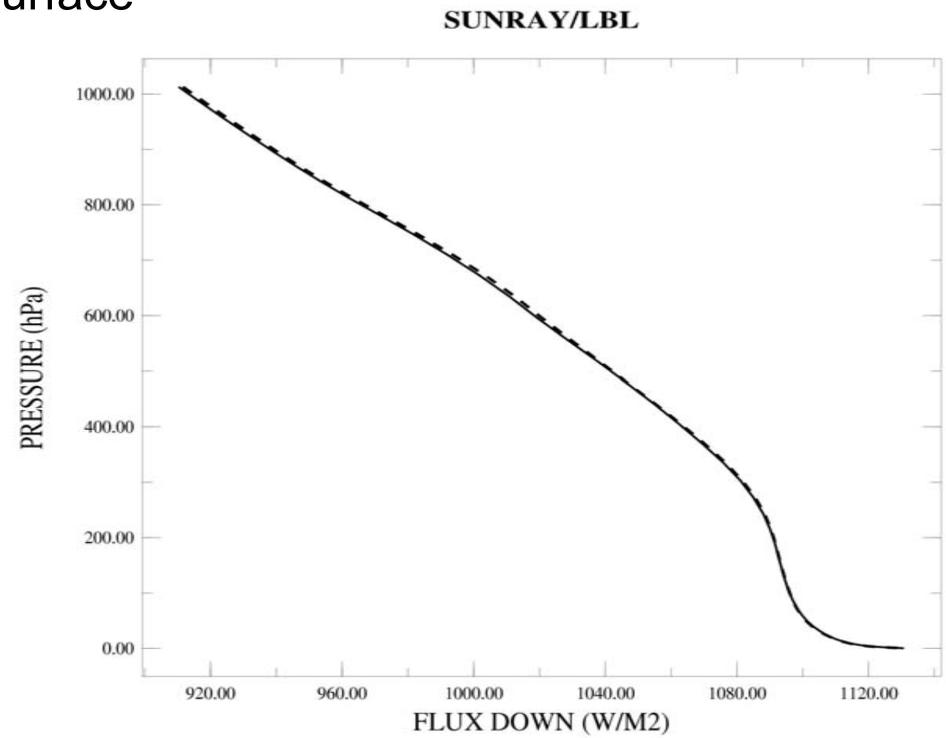
Impact of recent changes in RT schemes on the model high atmosphere

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

	SW6	SW
Solution of RT equation	two-stream method	two-stream method
	with Delta-Eddington approximation	with Delta-Eddington approximation
Limits of spectral intervals	6: 0.185 - 0.25 - 0.44	2: 0.25 - 0.69 - 4.0
	0.69 - 1.19 - 2.38 - 4.0	4: 0.25 - 0.69 - 1.19 - 2.38 - 4.0
Absorbers	H_2O, CO_2, O_3, O_2, CH_4, N_2O,	H_2O, CO_2, O_3, O_2, CH_4, N_2O,
	aerosols	aerosols
Spectroscopic database	HAWKS 2000	HITRAN 1992
Absorption coefficients	from line-by-line models	fits on statistical models of transmission
Cloud optical properties	σ_a, ω, g in each spectral interval	σ_a, ω, g in each spectral interval
Data		
ice clouds	Ebert & Curry, 1992	Ebert & Curry, 1992
water clouds	Fouquart, 1987	Fouquart, 1987
Cloud overlap assumption	maximum-random	maximum-random
Reference	Dubuisson et al., 1996 for LbL	Fouquart & Bonnel, 1980
		Morcrette, 1991, 1993

Impact of recent changes in RT schemes on the model high atmosphere

surface



Top of the atmosphere

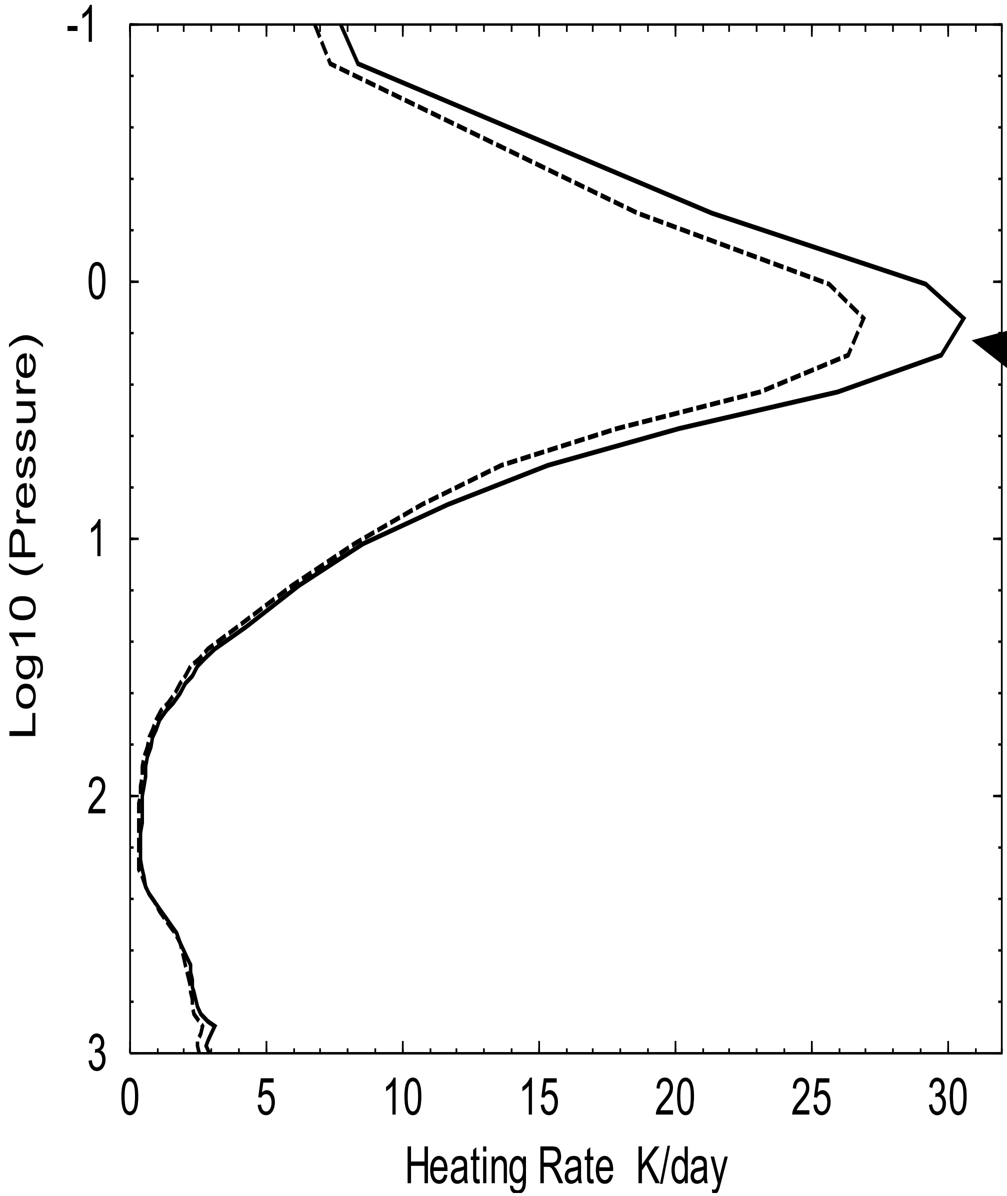
Comparison with a line-by-line model of the SW radiation transfer on standard cases shows an excellent agreement on the flux profiles

Standard tropical atmosphere:

full line = LbL
dash line = SW6

2001

Impact of recent changes in RT schemes on the model high 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 μ_0=0.8)

Larger SW heating at stratopause

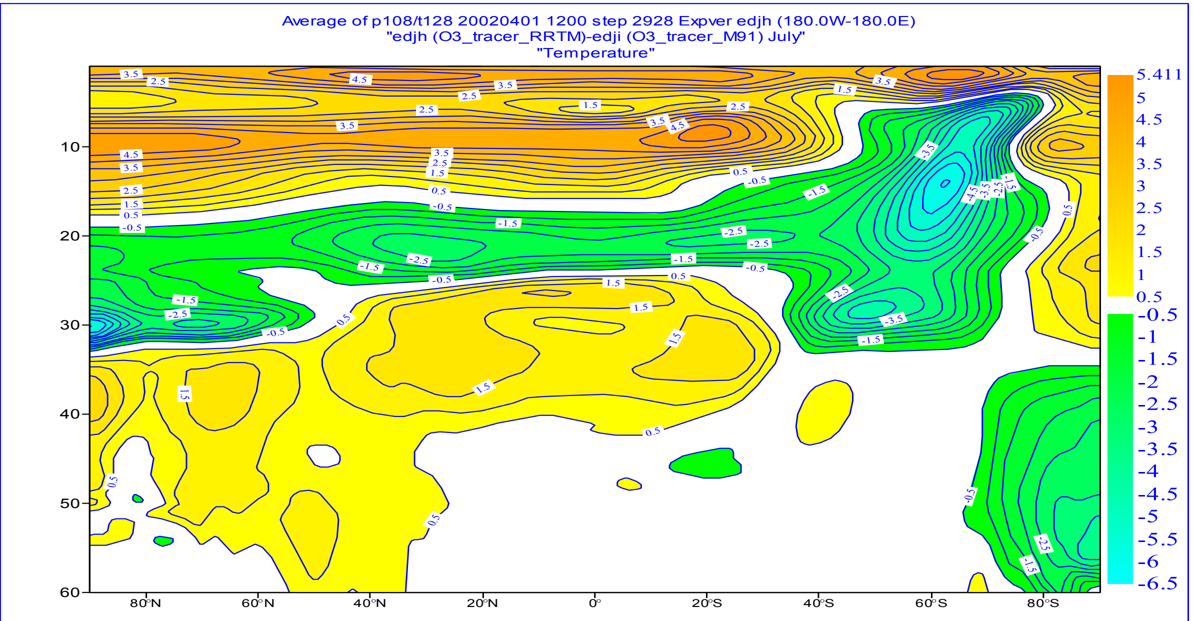
Experimentation

- Series of 4-month $T_L159L60$ starting 20020401 (OPE)
  - Results presented as zonal means of T, q, CF, O_3

- Series of 20-month $T_L159L60$ integrations starting 20000401 (ERA40)
  - Results presented as time-series of data averaged over the 90^oN-60^oN, 30^oN-30^oS, and 60^oS-90^oS 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



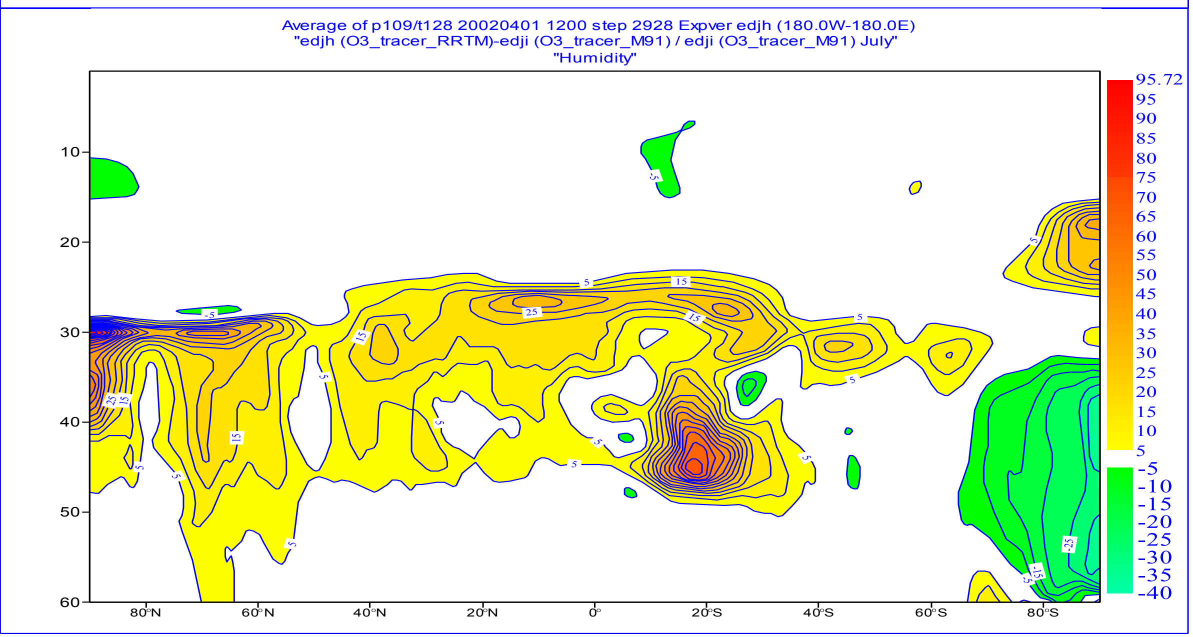
July:

Impact of change of LW radiation scheme for **climatological O_3** in RT

RRTM - M91/G00

Both simulations with SW6

Temperature difference ΔT in K



relative difference in humidity $\Delta q/q$ in %

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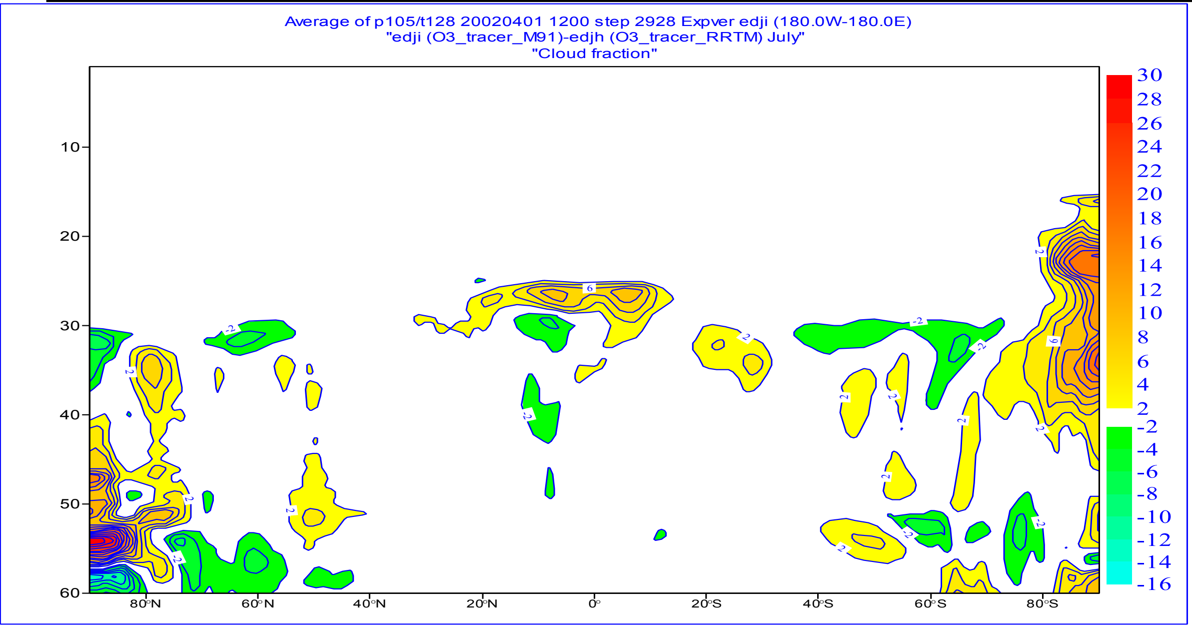
Impact of change in LW-RT scheme on the model high atmosphere



July:

Impact of change of LW radiation scheme for **climatological O_3** in RT

RRTM - M91/G00

Both simulations with SW6

Cloud fraction difference ΔCC 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

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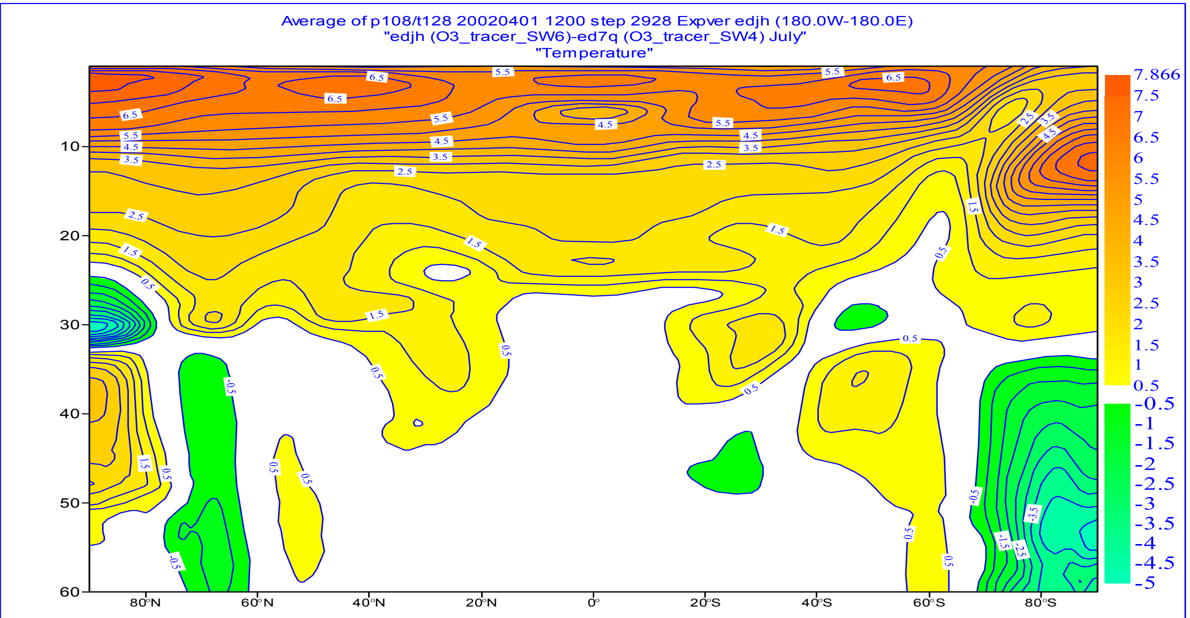
Impact of change in SW-RT scheme on the model high atmosphere



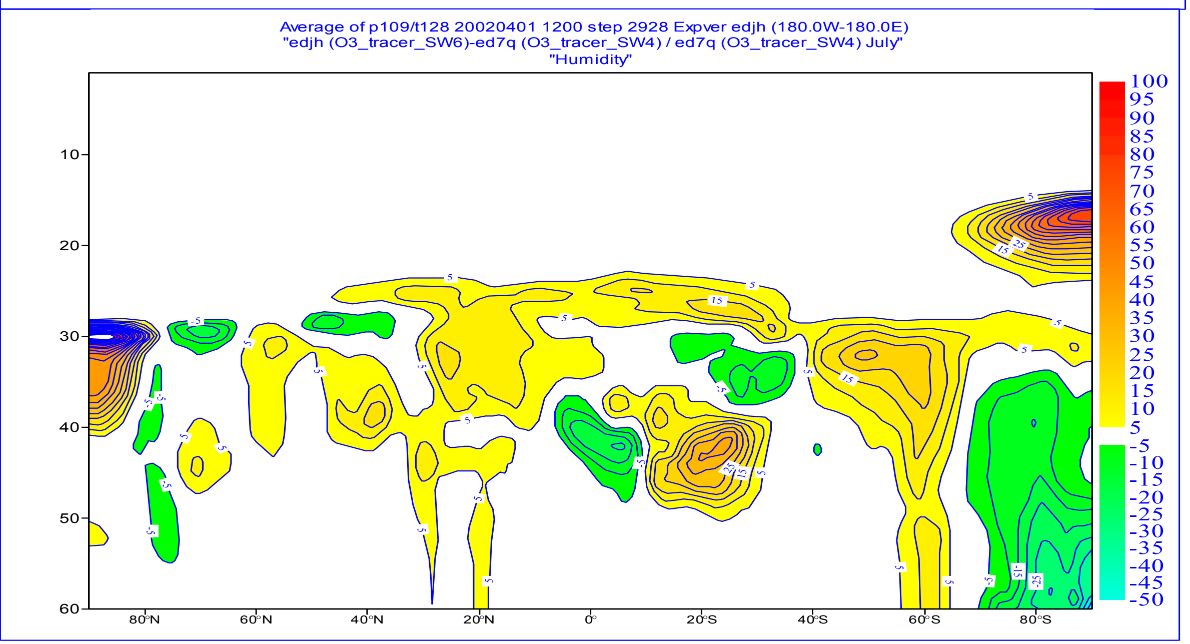
July:

Impact of change of SW radiation scheme for **climatological O_3** in RT

SW6 – SW4

Both simulations with RRTM

Temperature difference ΔT in K

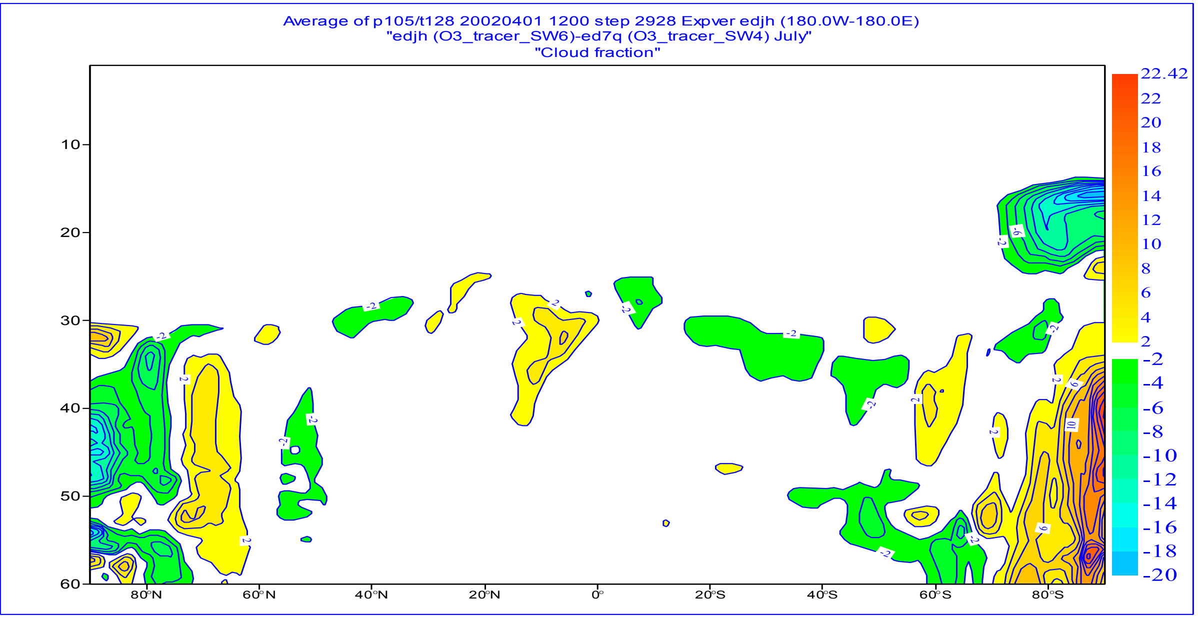


relative difference in humidity

$\Delta q/q$ in %

ECMWF

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

Cloud fraction difference ΔCC in %

Through an increase absorption by stratospheric O_3 and tropospheric H_2O (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?

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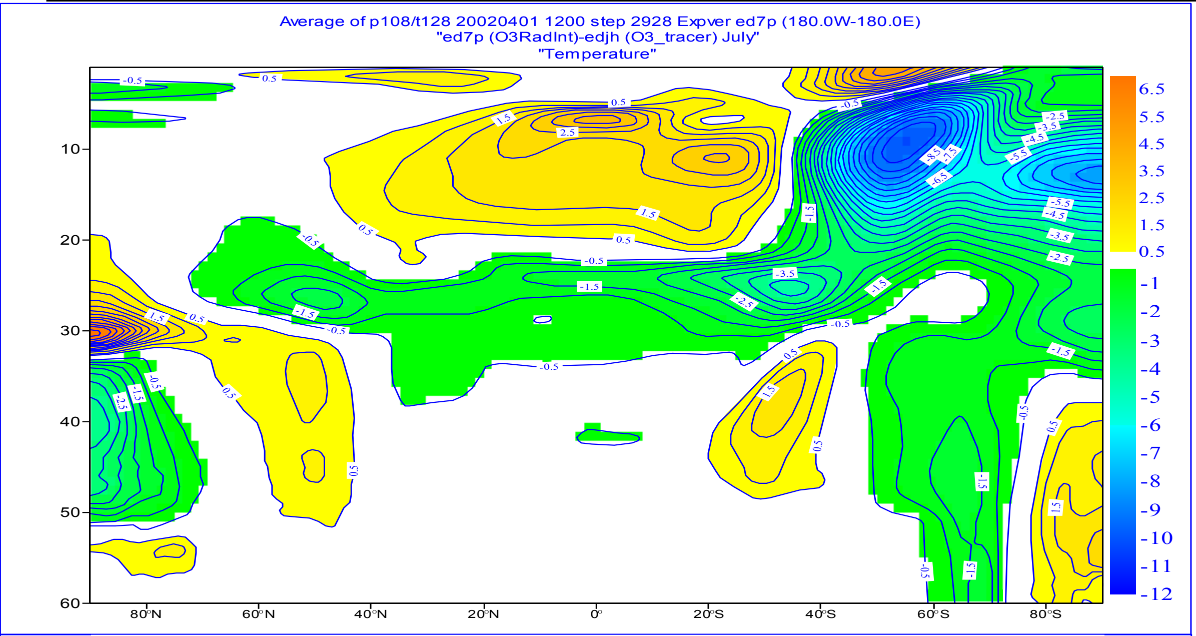
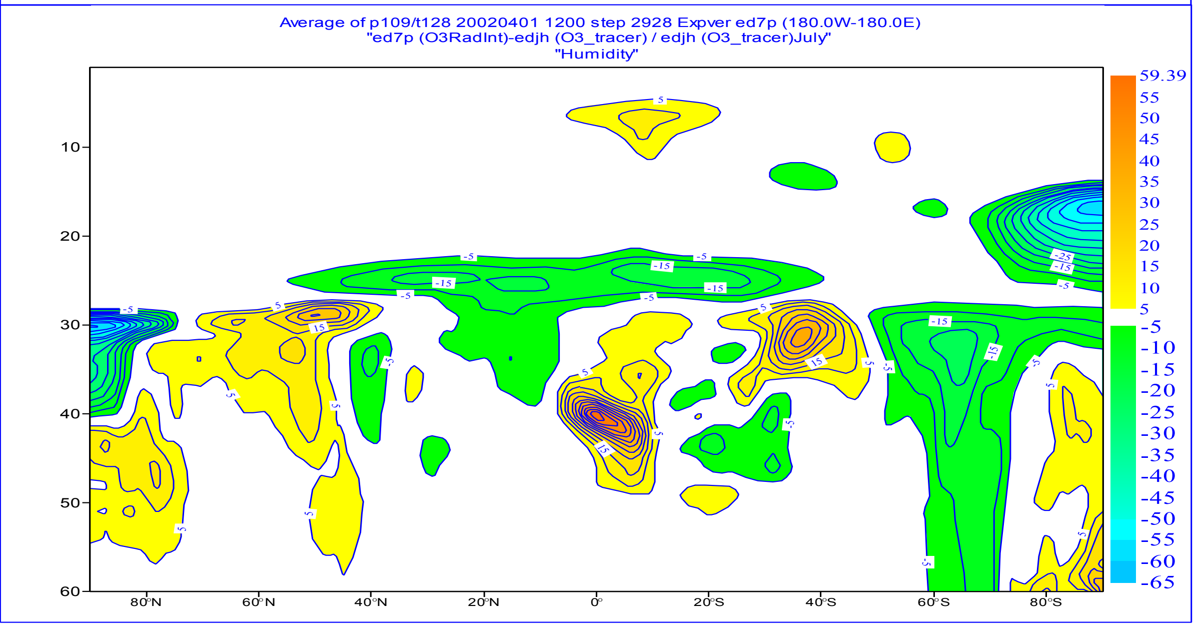
Impact of interactions between prognostic ozone and radiation





July:

RRTM, SW6

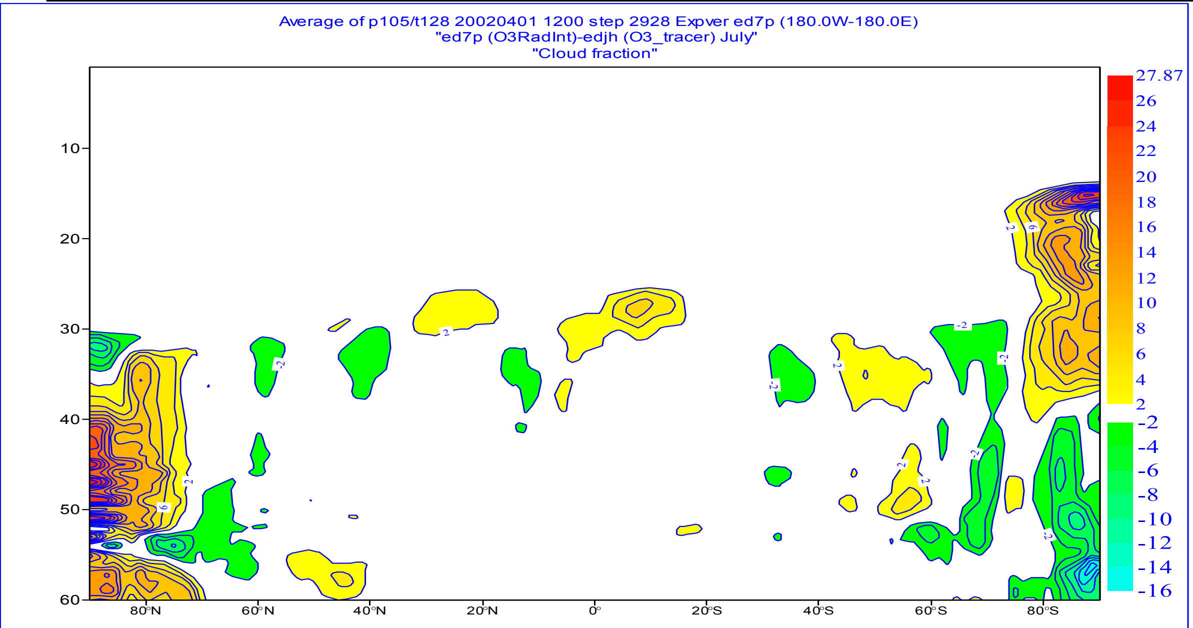
O_3_RadInt – O_3_clim

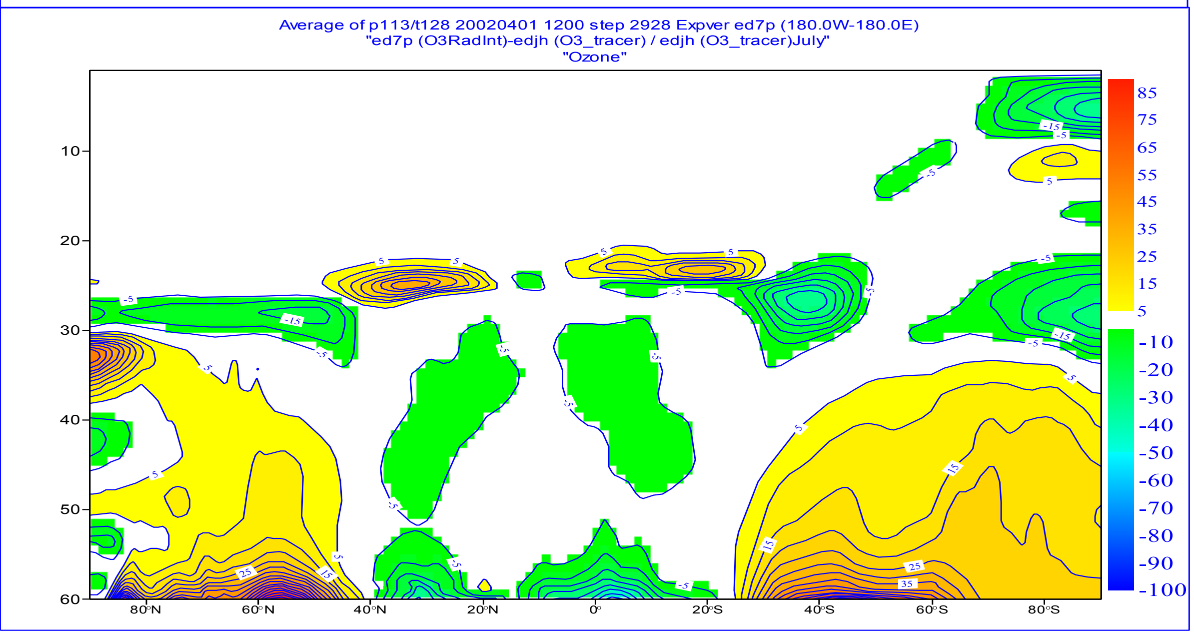
Temperature difference ΔT in K

relative difference in humidity $\Delta q/q$ in %

ECMWF

Impact of interactions between prognostic ozone and radiation





July:
RRTM, SW6

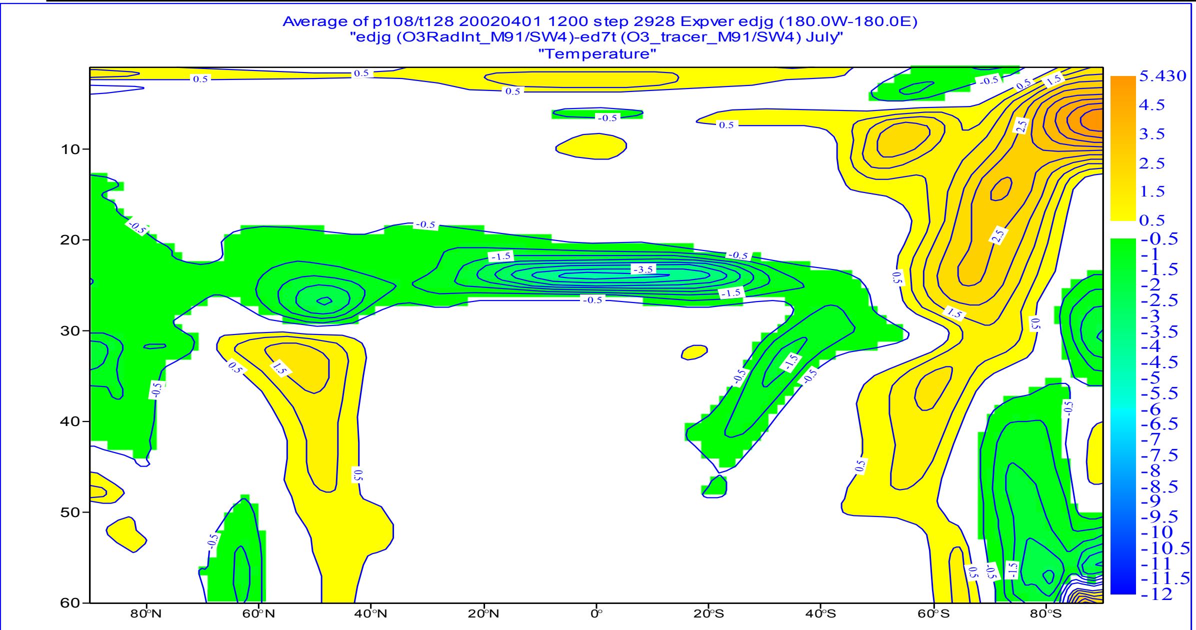
O_3_RadInt – O_3_clim

Cloud fraction difference ΔCC in %

relative difference $\Delta q_{O3}/q_{O3}$ in %

ECMWF

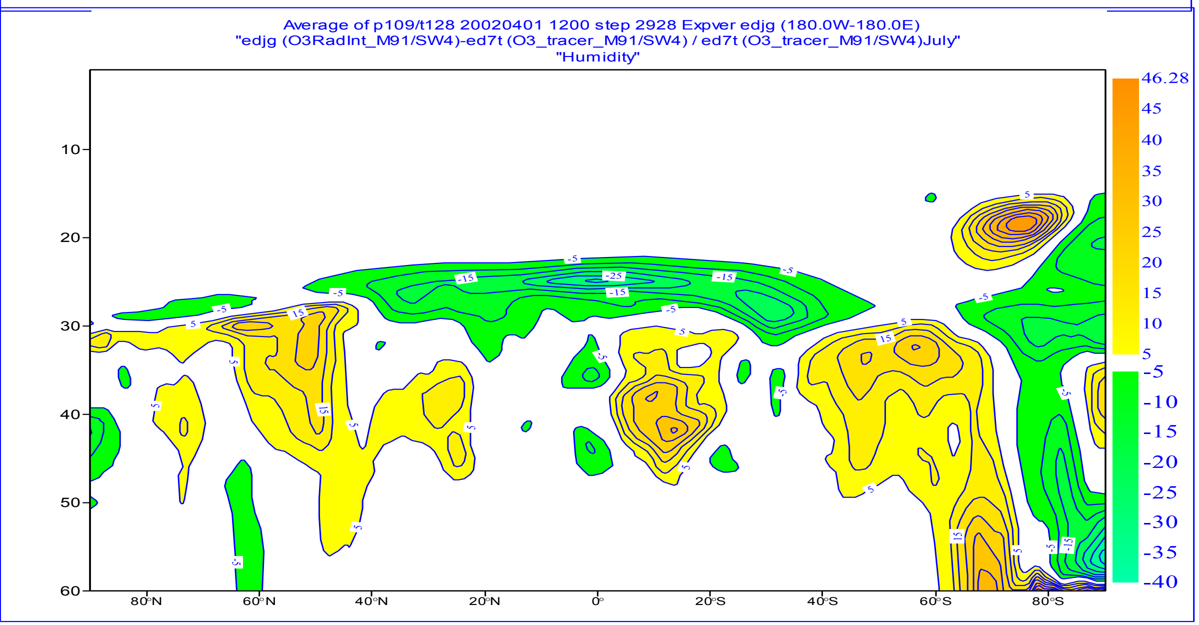
Impact of interactions between prognostic ozone and radiation



July:
M91/G00, SW4

O_3_RadInt – O_3_clim

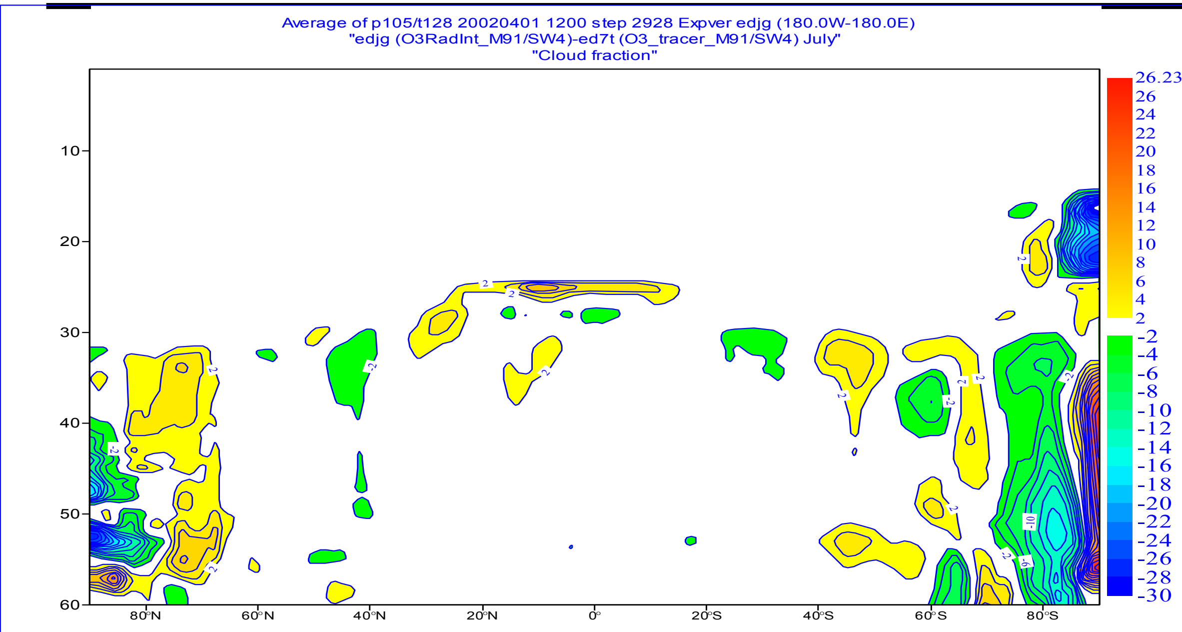
Temperature difference ΔT in K

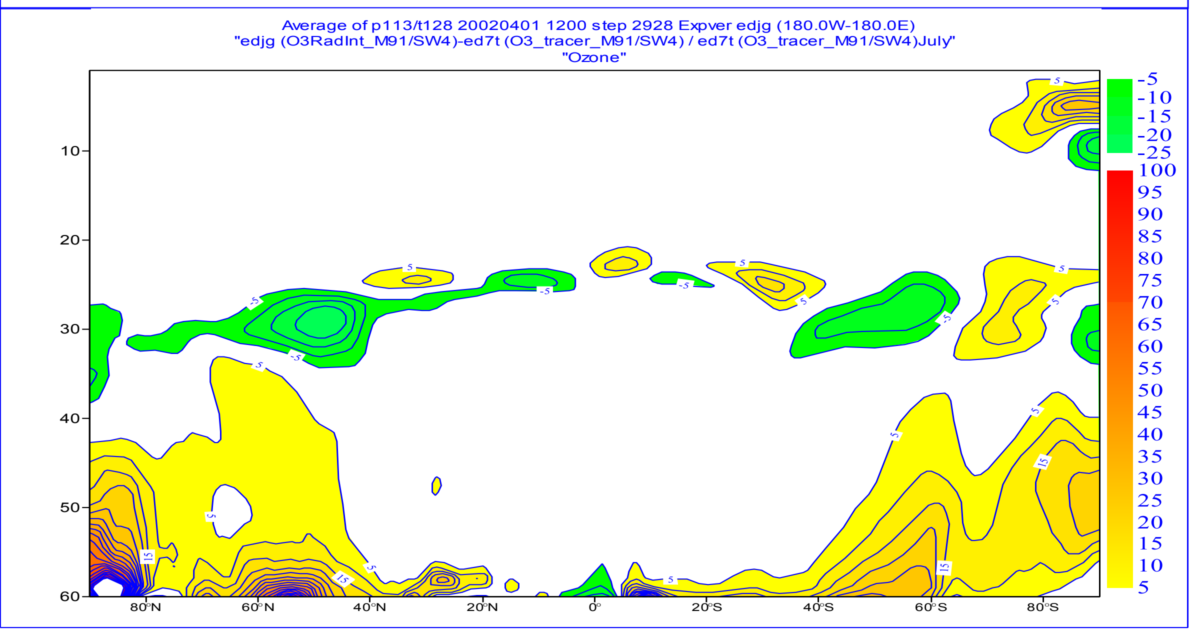


relative difference in humidity Δq/q in %

ECMWF

Impact of interactions between prognostic ozone and radiation





July:

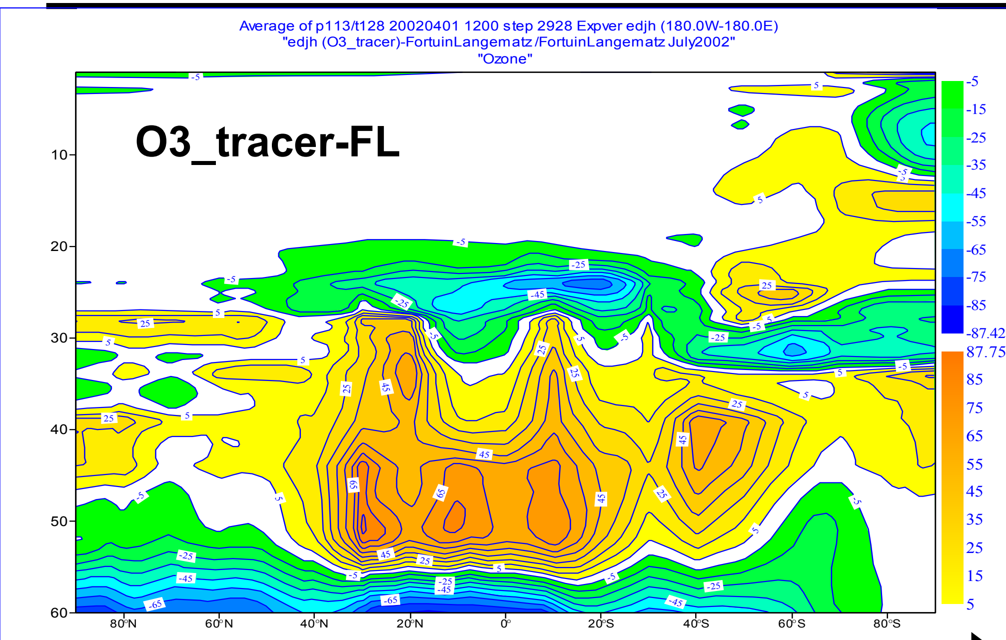
M91/G00, SW4

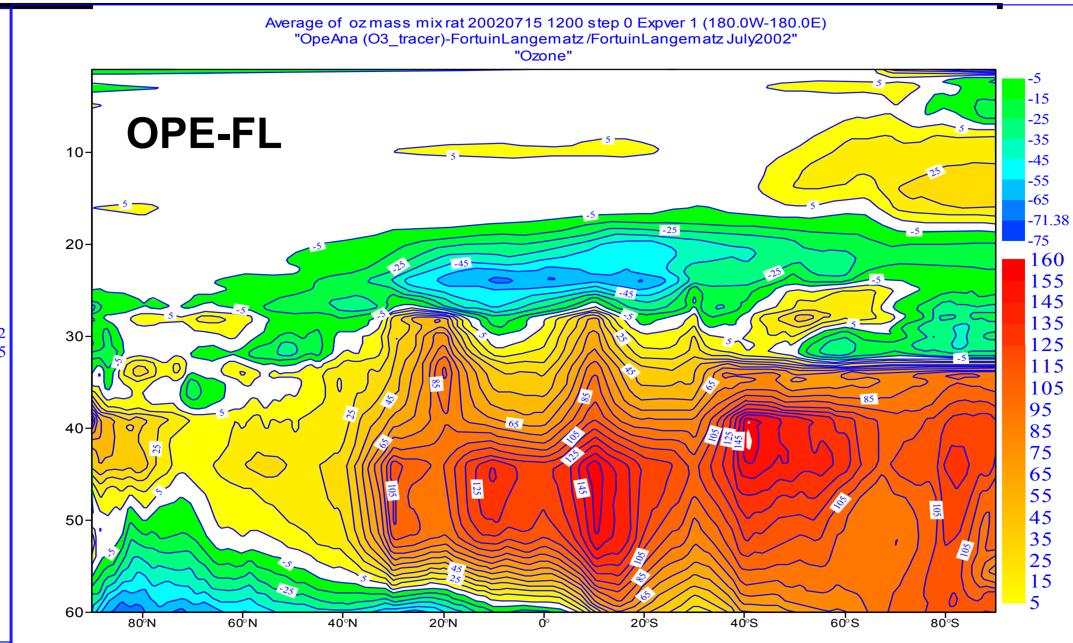
O3_RadInt – O3_clim

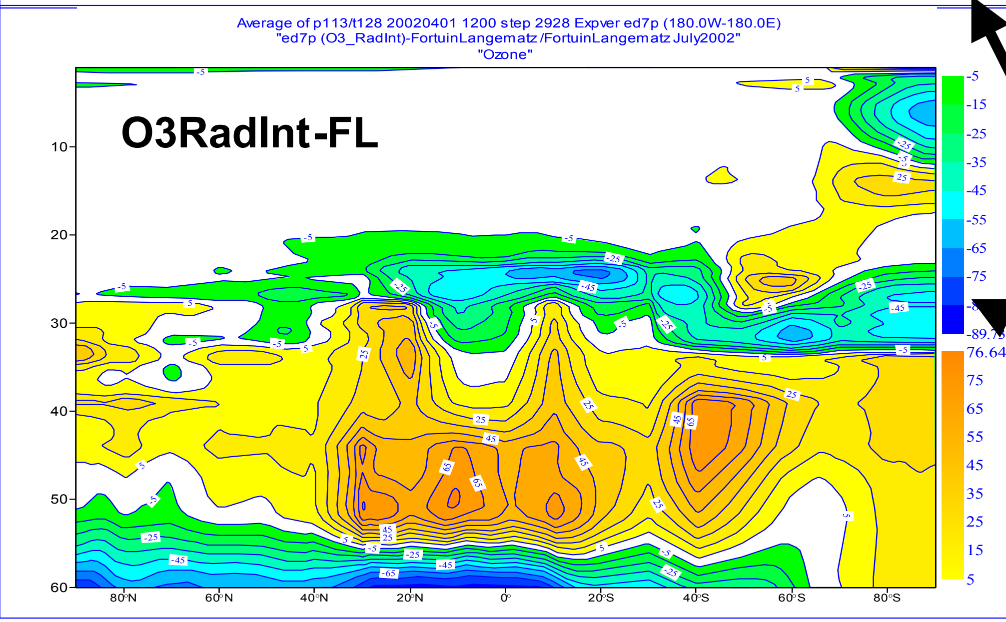
Cloud fraction difference ΔCC in %

relative difference $\Delta q_{O3}/q_{O3}$ in %

Comparison between prognostic ozone and Fortuin-Langematz's ozone climatology for July







T_L511L60
Initial conditions
July 2002

T_L159L60 started 200204

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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

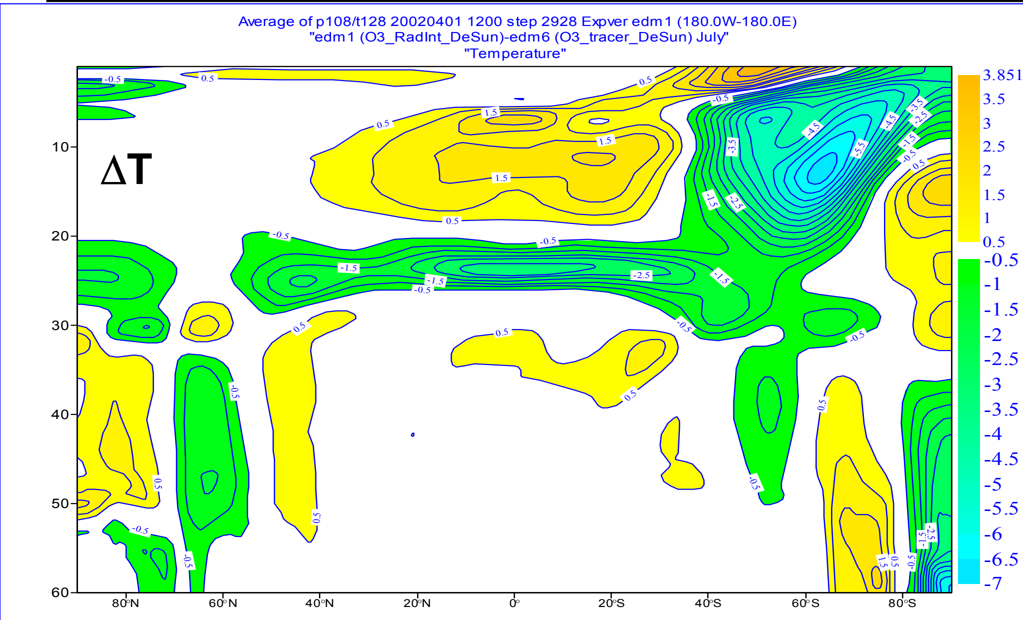
* Within the LW and SW radiation schemes, the high cloud optical properties depend on:
-the ice water content (and ice water path once integrated over the thickness of the layers)
- a model of cloud optical properties, itself dependent on
- the effective size of the ice particles

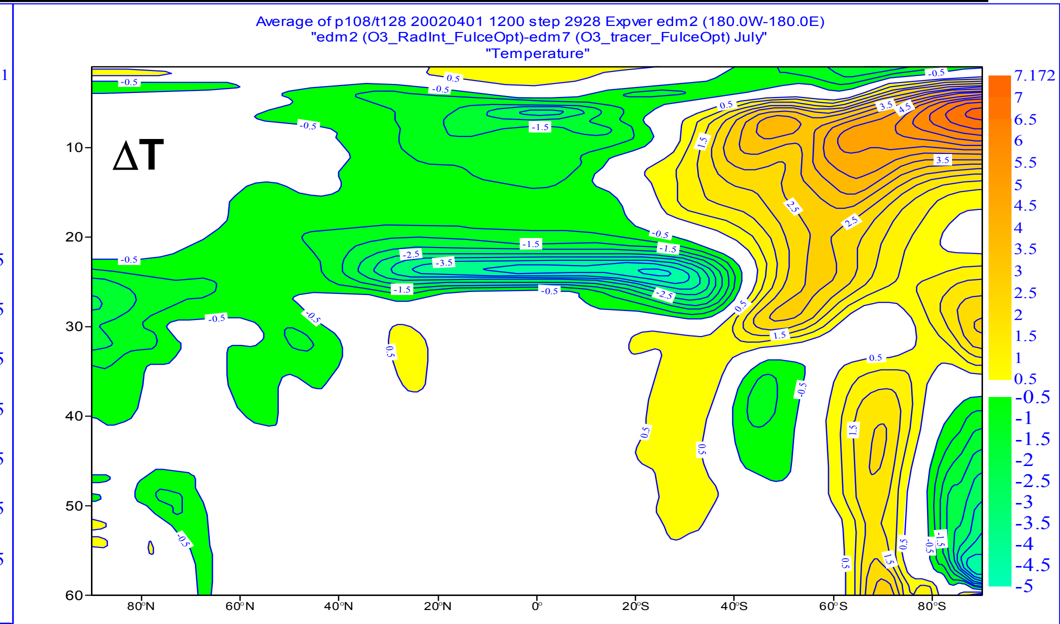
* The operational version of the ECMWF model uses:
- cloud optical properties from Ebert & Curry (1992)
- effective particle size De diagnosed from temperature between 30 and 60 μm from Ou and Liou (1995)

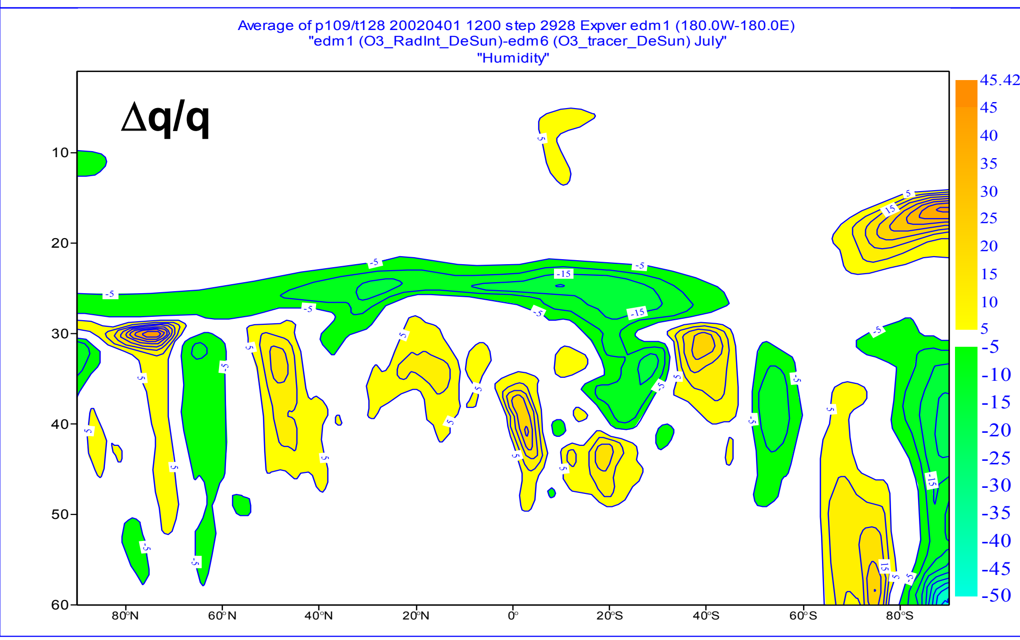
* Results are presented with the alternate:
- cloud optical properties from Fu (1996) in the SW, and Fu et al. (1998) in the LW
- effective particle size diagnosed from both temperature and ice water content following Sun (2001) making particle size De vary between 15 and 150 μm.

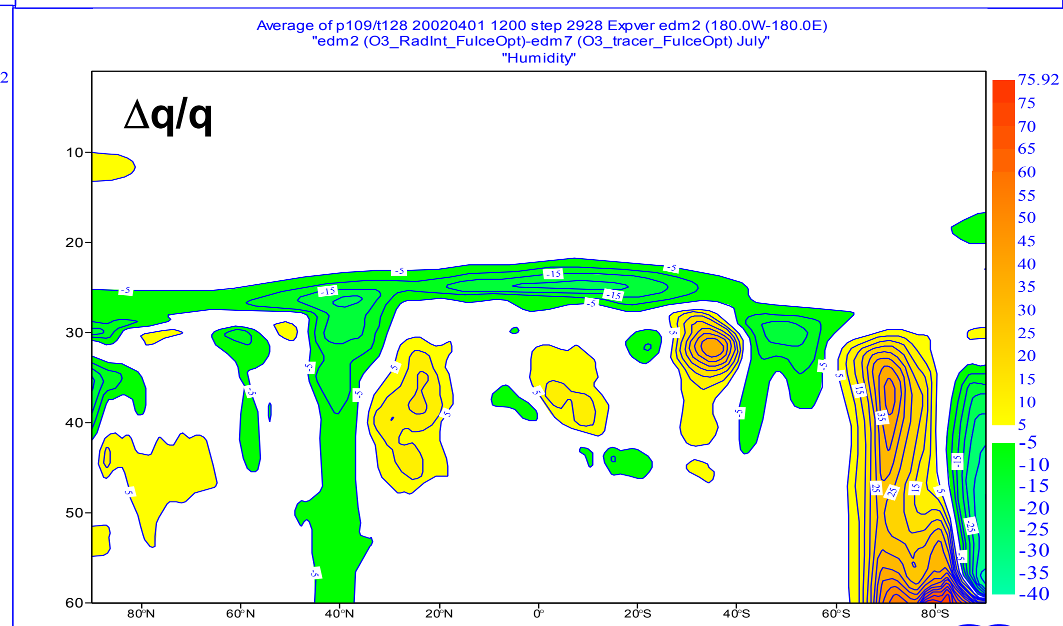
Impact of representation of high cloudiness:

change in De / change in ice cloud optical properties



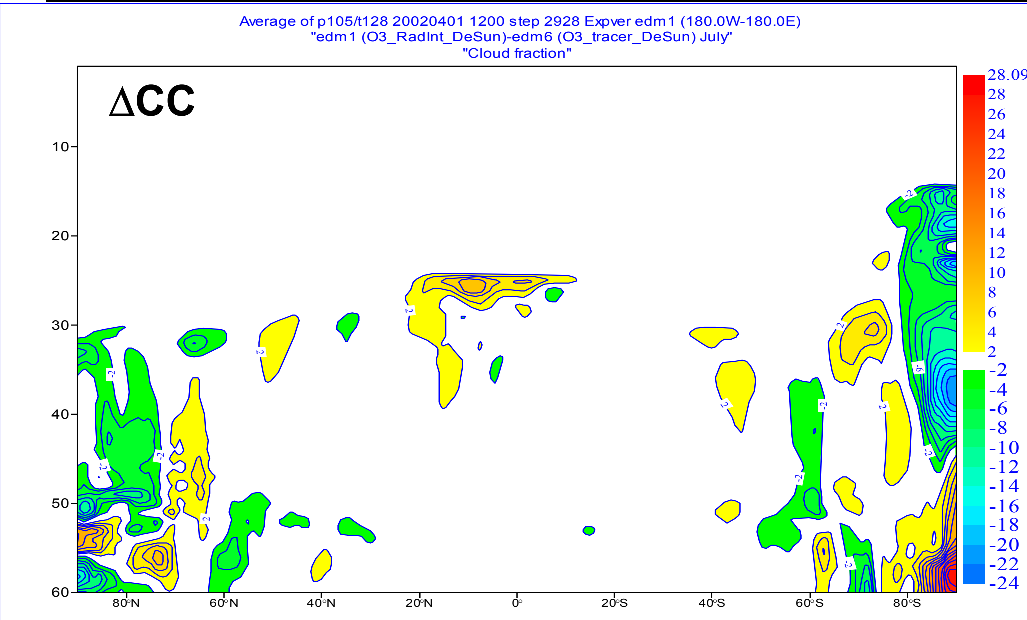


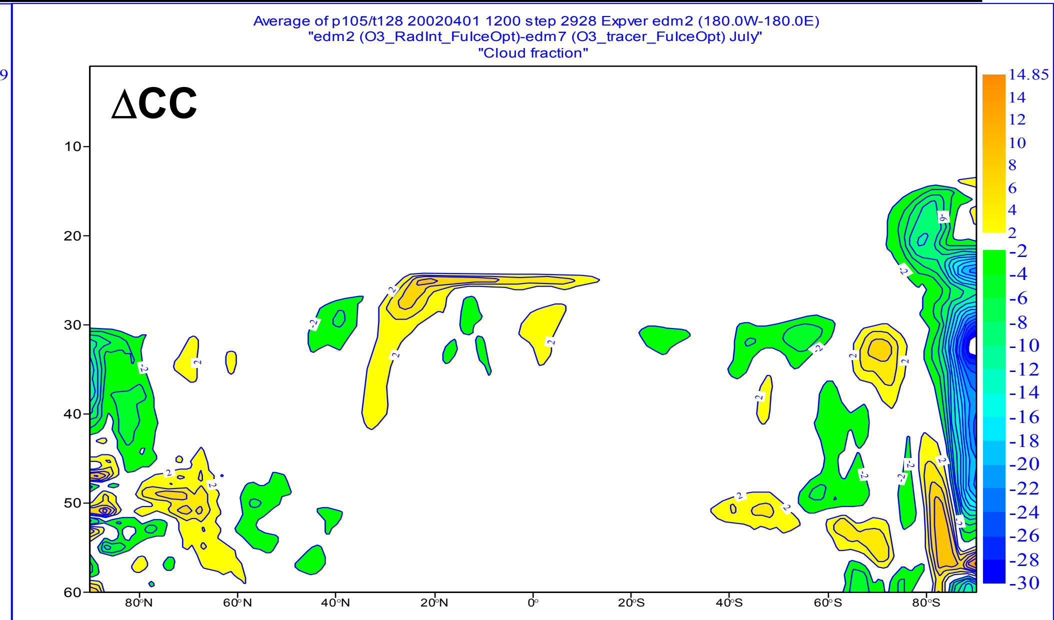


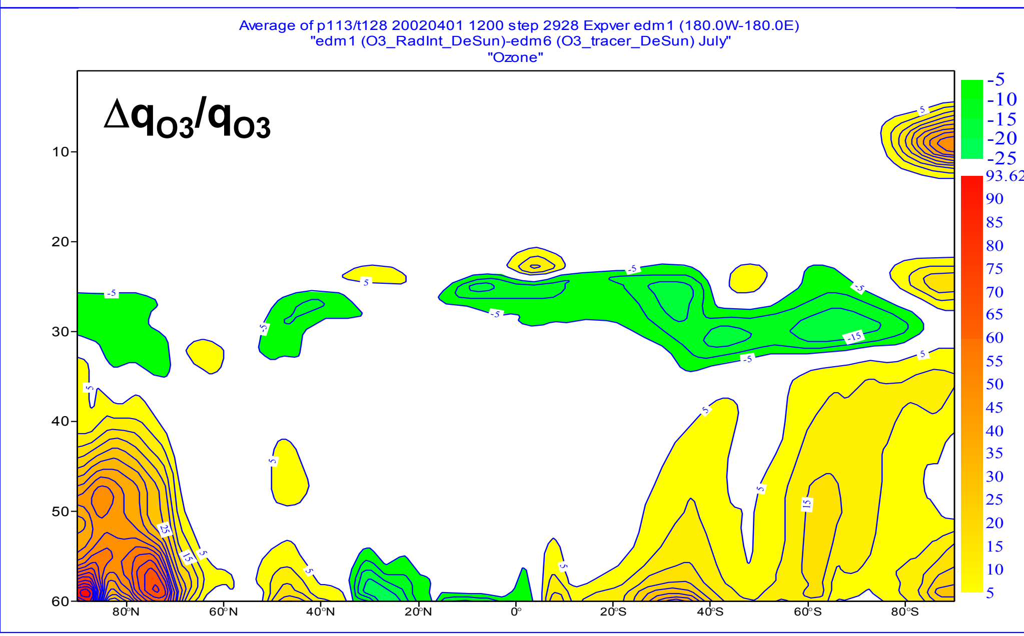


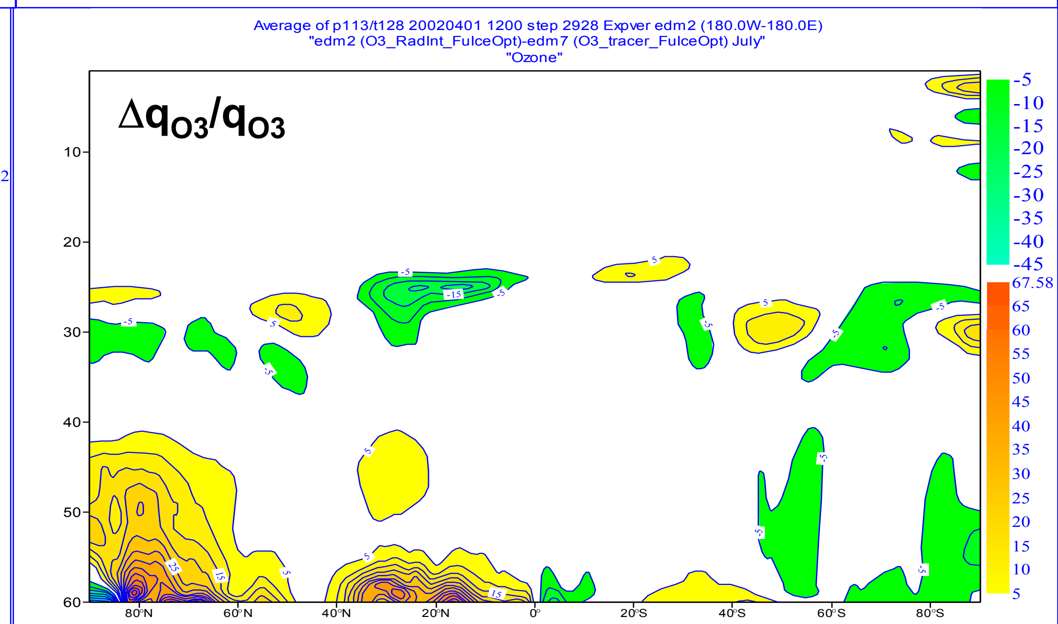
Impact of representation of high cloudiness:

change in De — change in ice cloud optical properties









Impact of representation of high cloudiness: change in De change in ice cloud optical properties

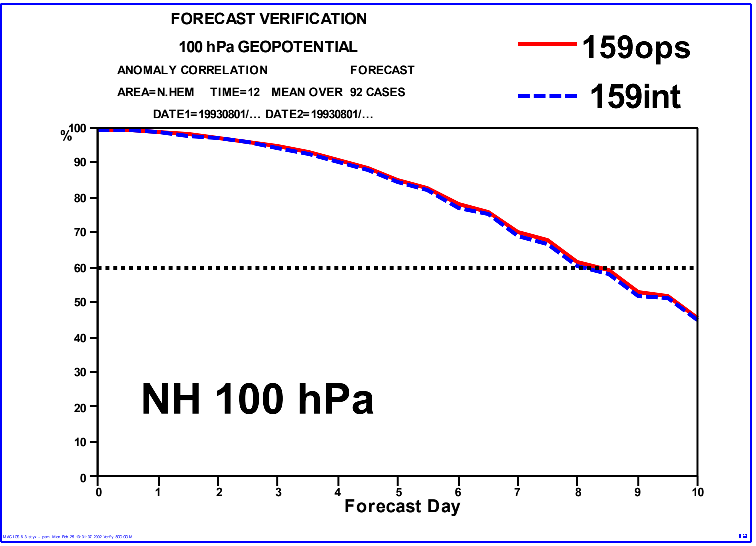
Changing the details of the representation of the RT in the ice clouds, which affect the actual Temperature and humidity in the upper tropospheric layers, does not significantly change the Response of the model when going from O3_clim to O3RadInt.

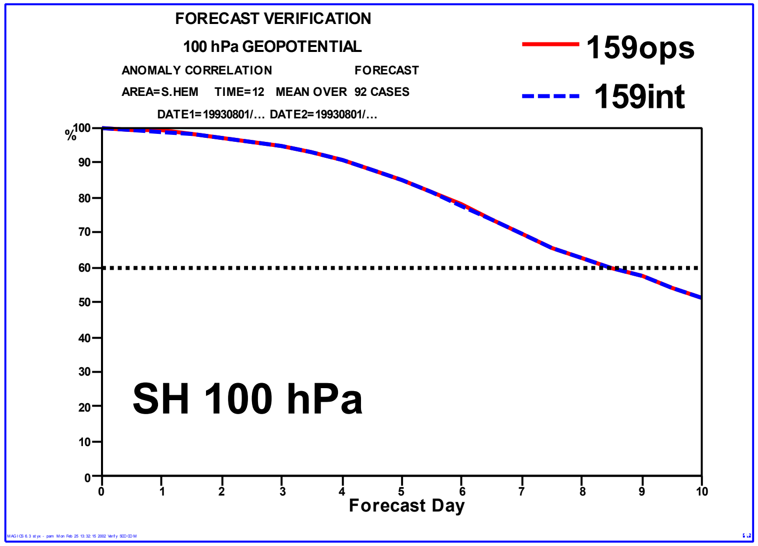
The main contributor is the much different prognostic O_3 amount w.r.t. the Fortuin-Langematz climatology on which radiation has been computed when O_3 is a tracer

Impact of O3/radiation interactions on objective scores
Comparisons with ozonesonde measurements

- Series of 10-day T_L159L60 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

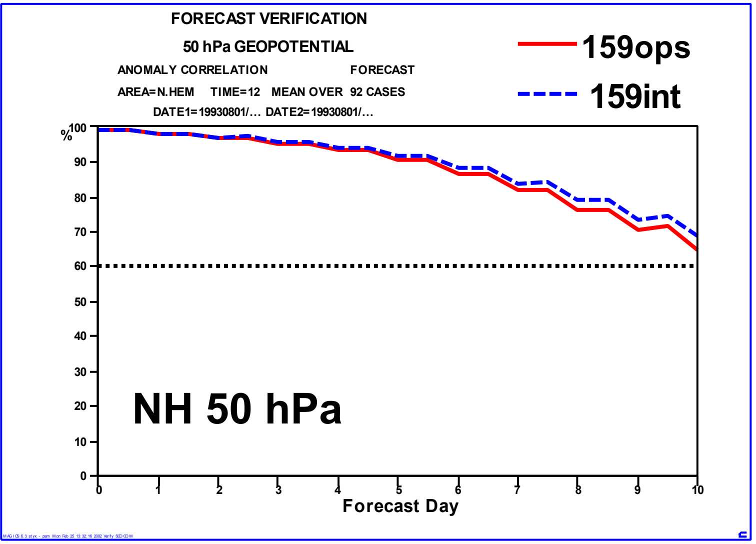
Objective scores: Anomaly correlation of Z at 100 and 50 hPa

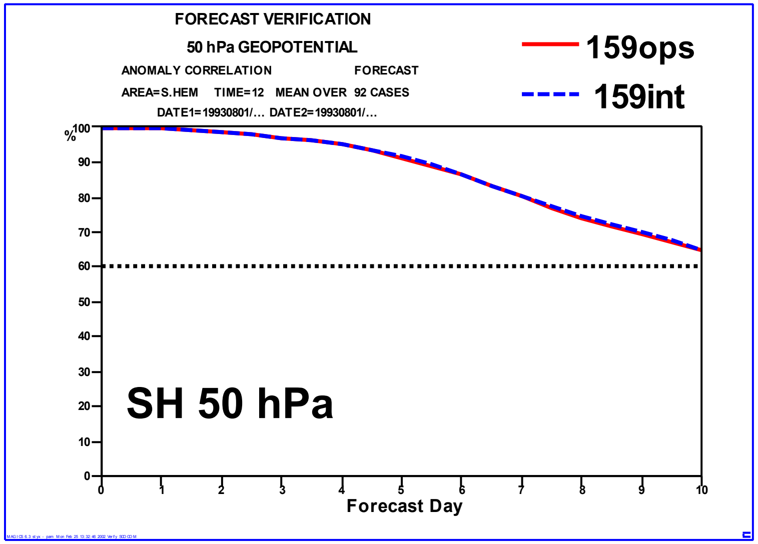




T_L159L60 10-day forecasts started from ERA40 reanalysis:
92 FCs between 19930801 and 19931031

Model cycle 23r4

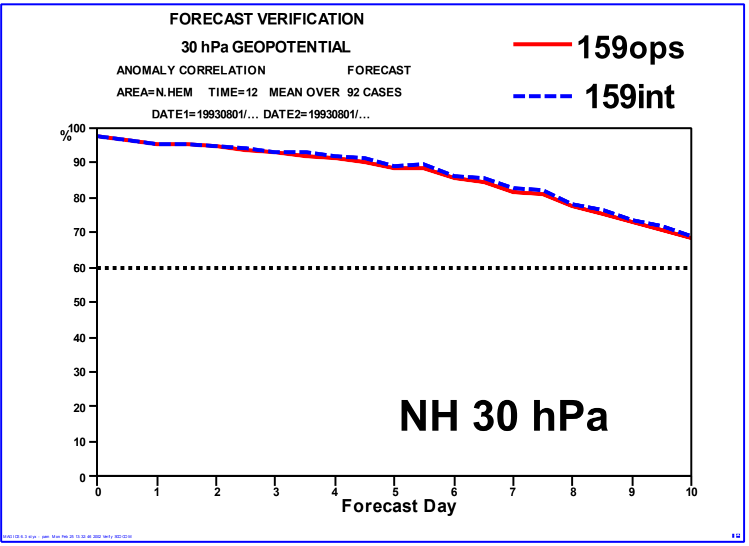


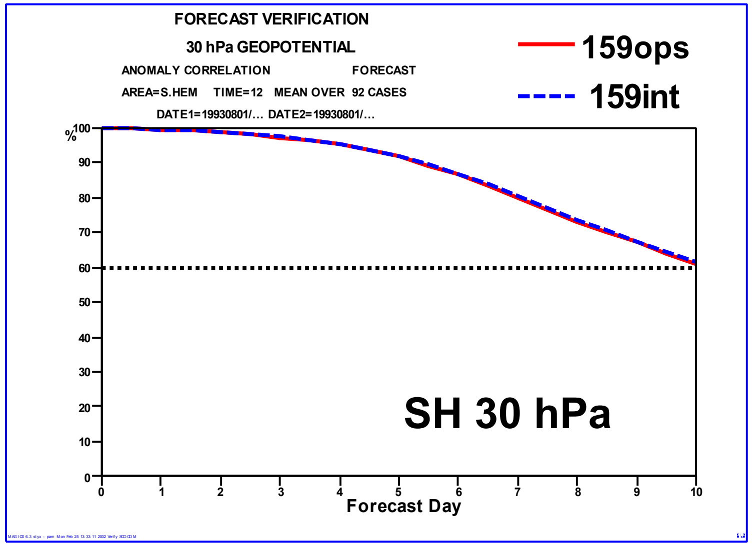


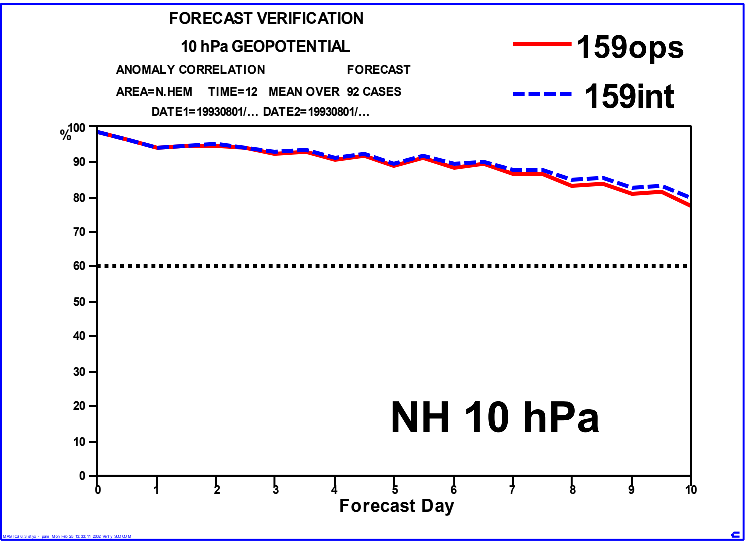
O3_clim

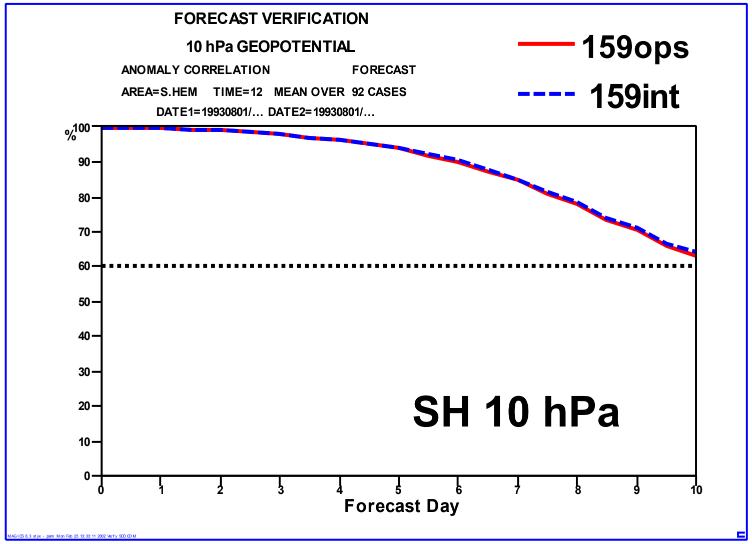
O3RadInt

Objective scores: Anomaly correlation of Z at 30 and 10 hPa





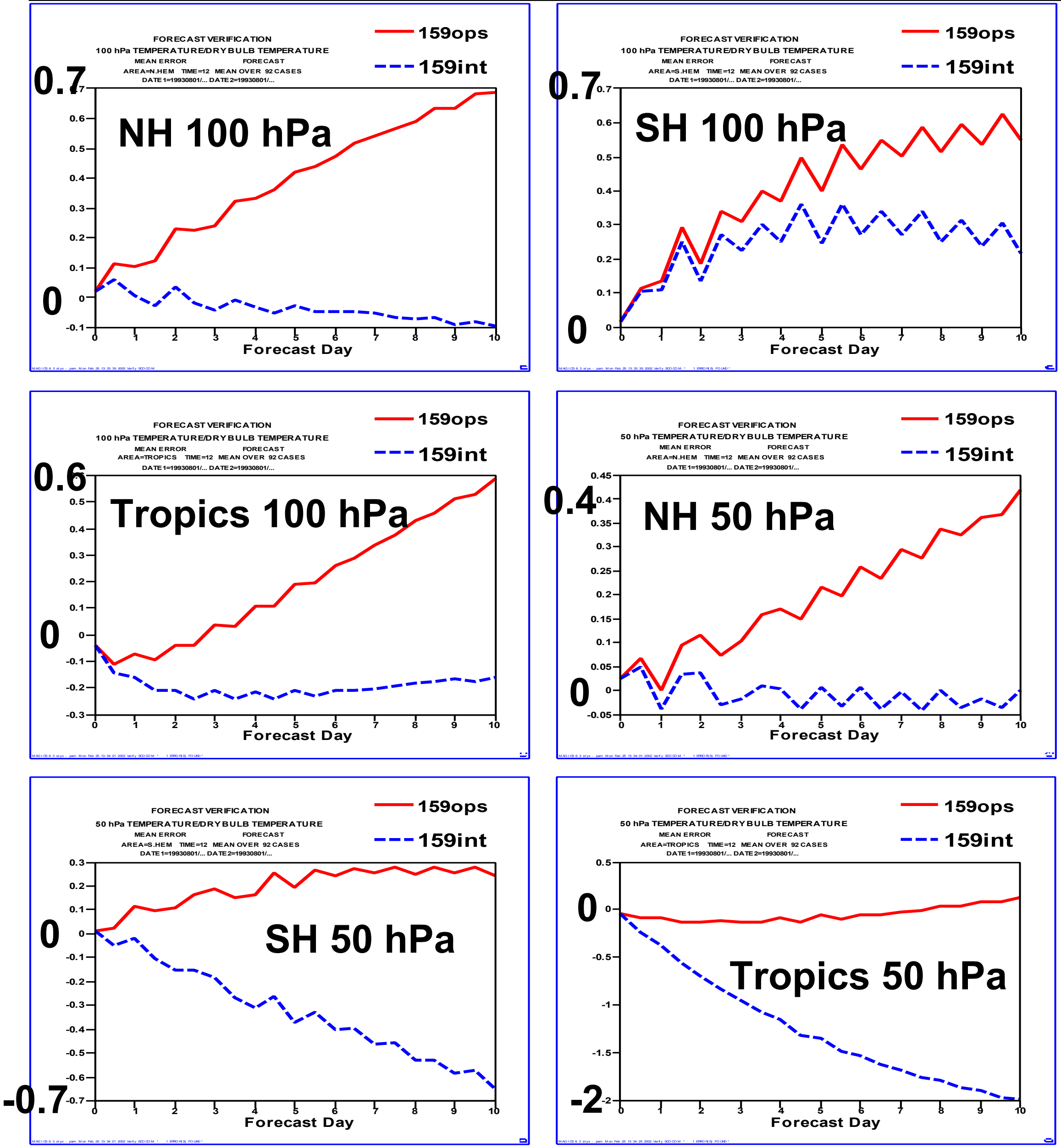




O3_clim

O3RadInt

Objective scores: mean error in T at 100 and 50 hPa



O3_clim

O3RadInt

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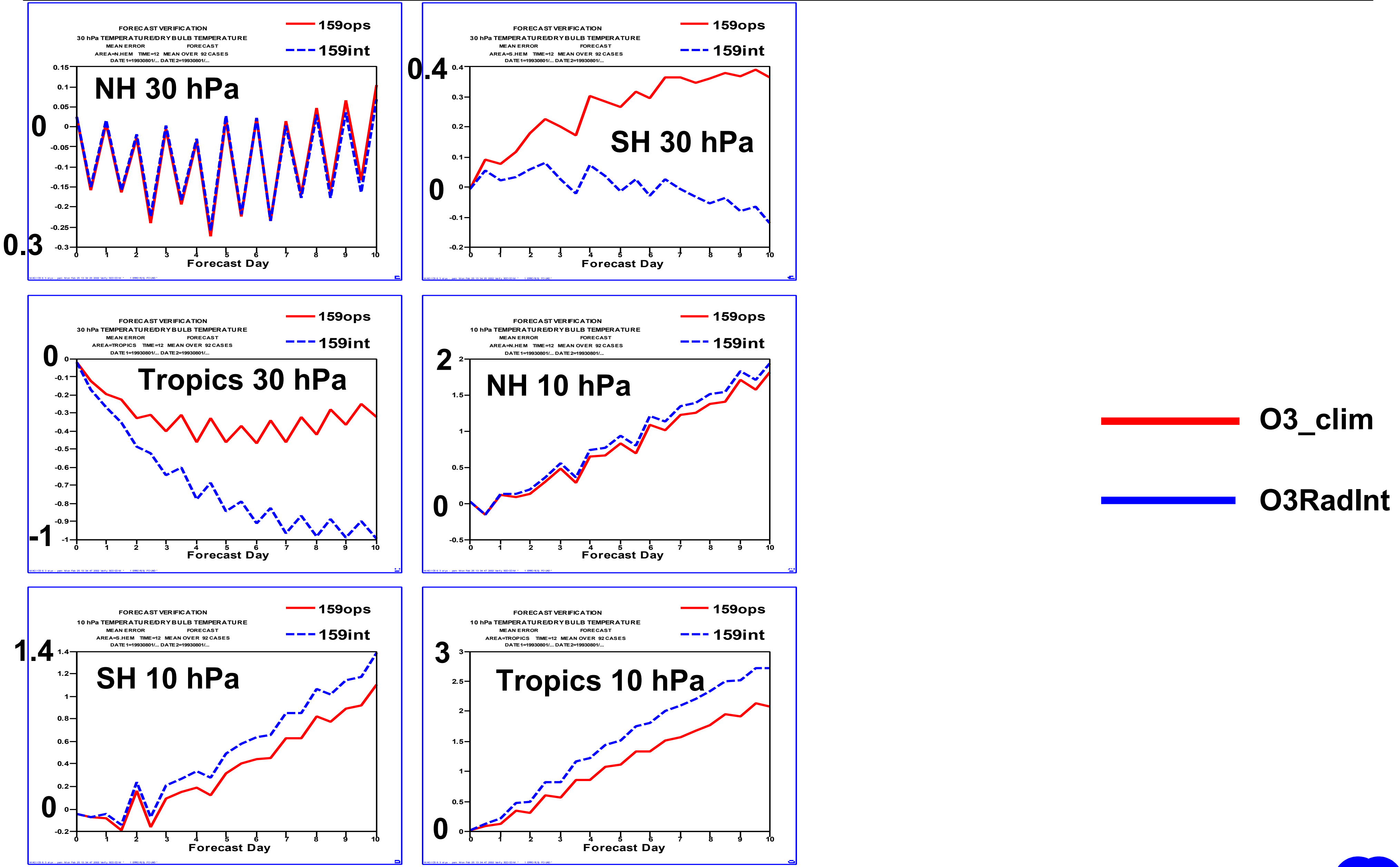
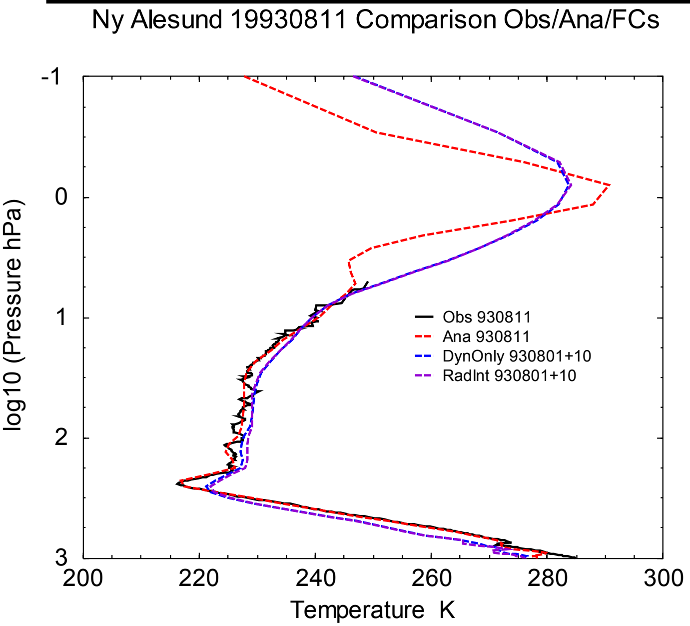
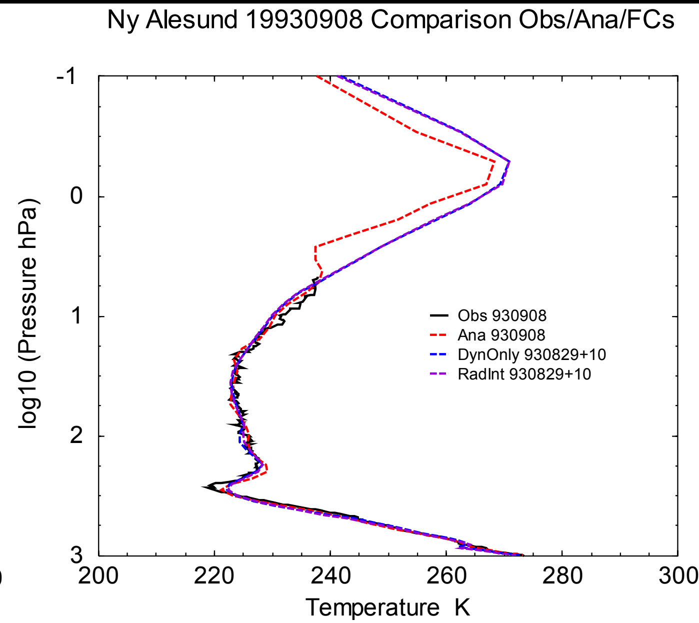
Objective scores: mean error in T at 30 and 10 hPa

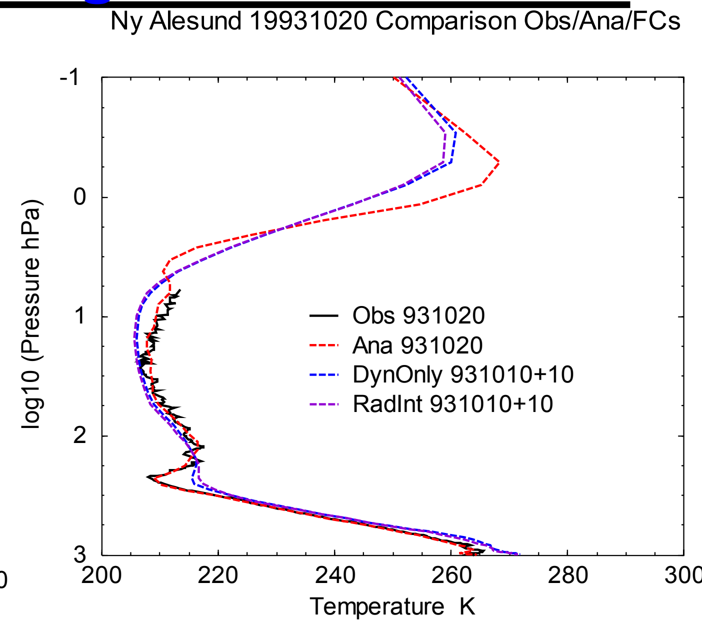


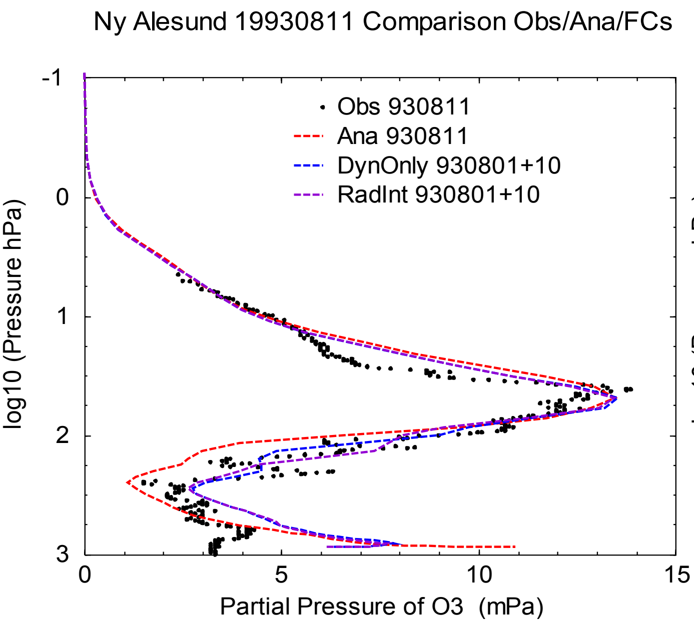
ECMWF

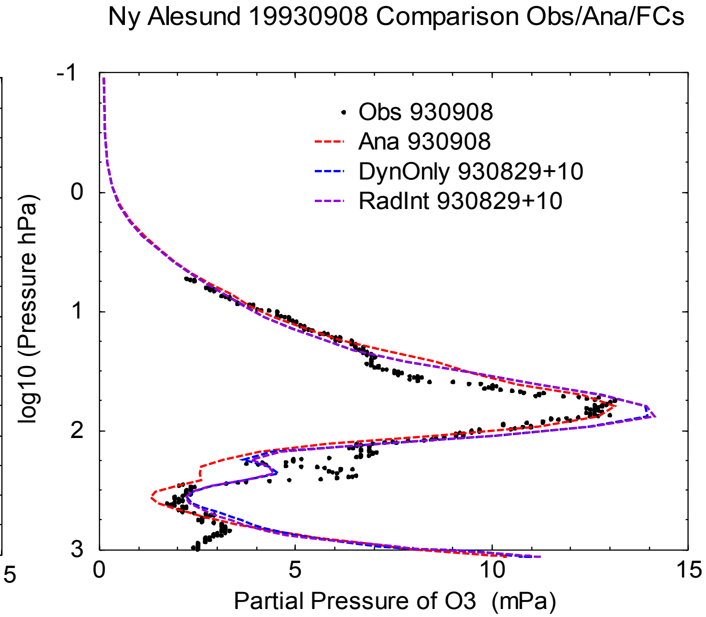
Comparison with T and O_3 profiles from ozonesondes:
Ny Alesund: 78.39N 11.88E (Svalbard) August-October 1993

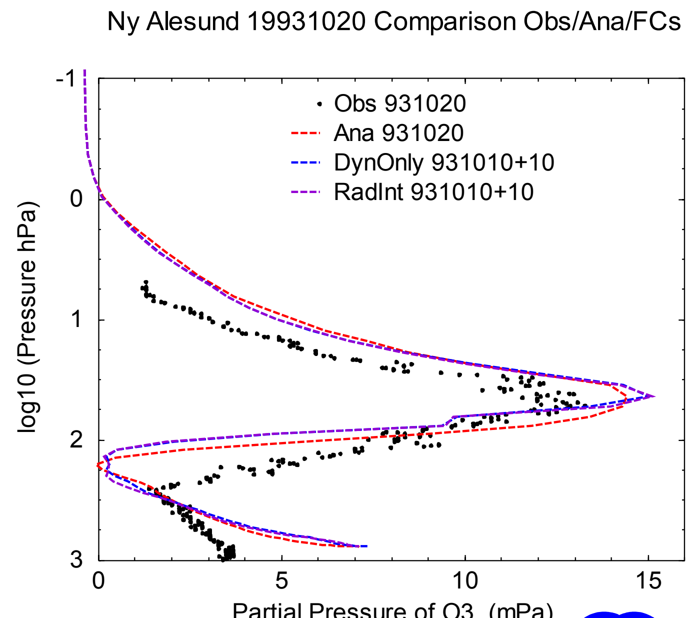




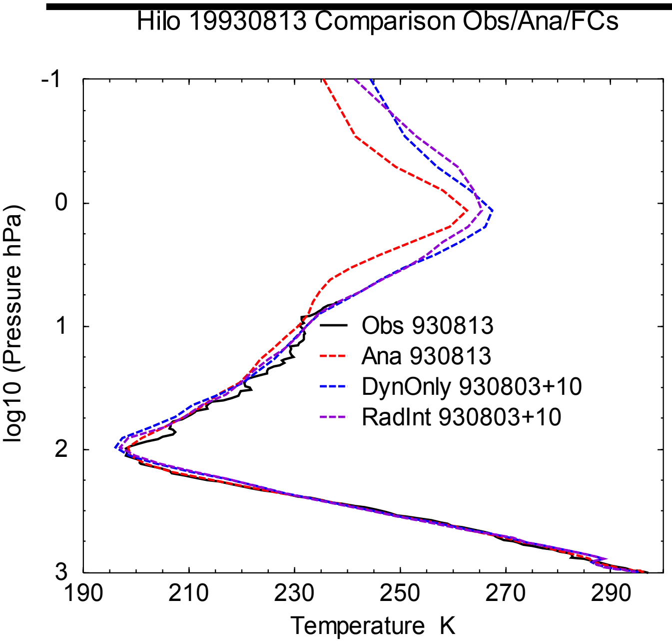


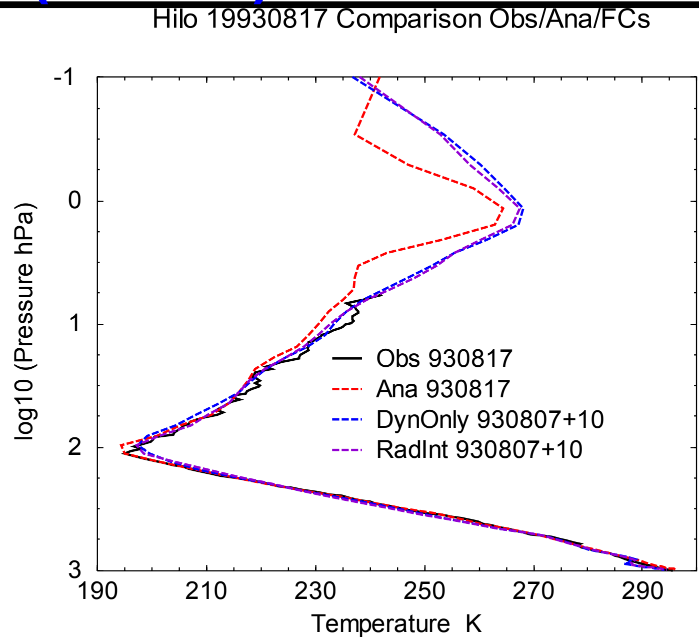


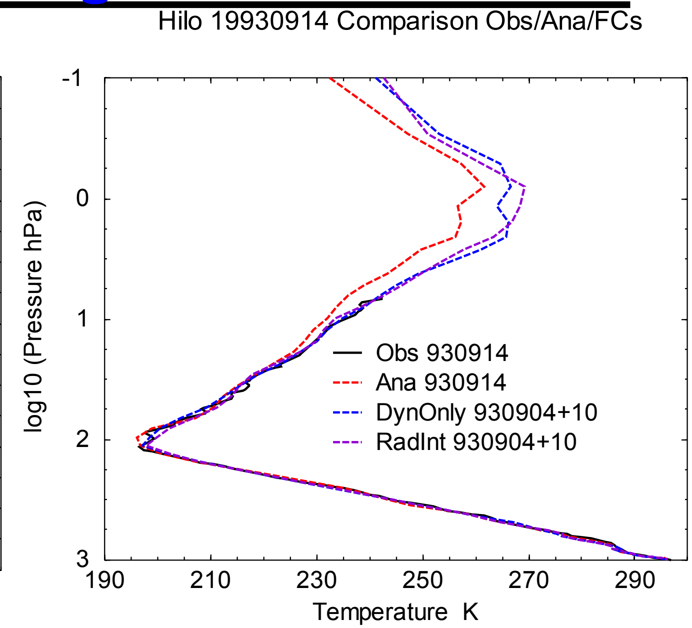


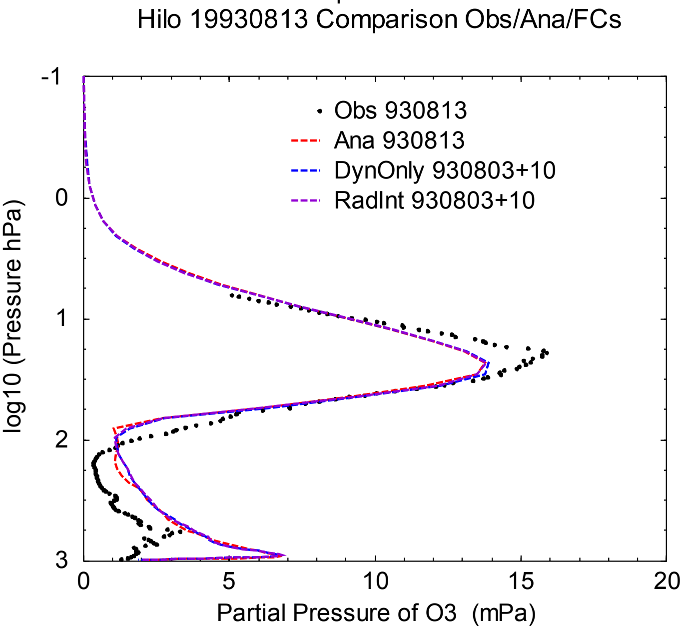


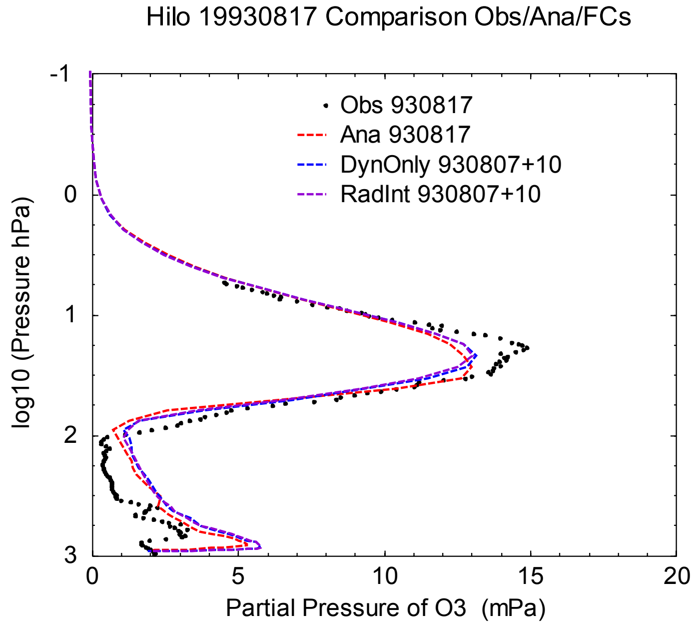
Comparison with T and O_3 profiles from ozonesondes: Hilo: 19.72N 155.08E (Hawaii) August-October 1993

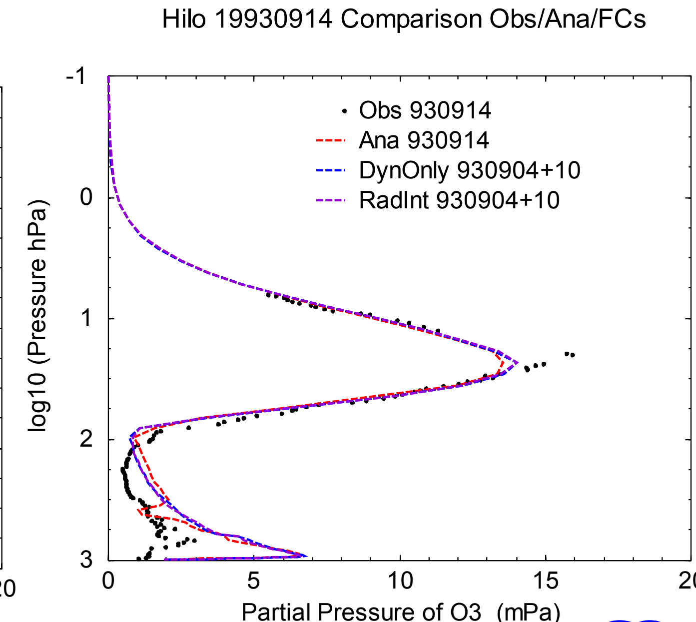




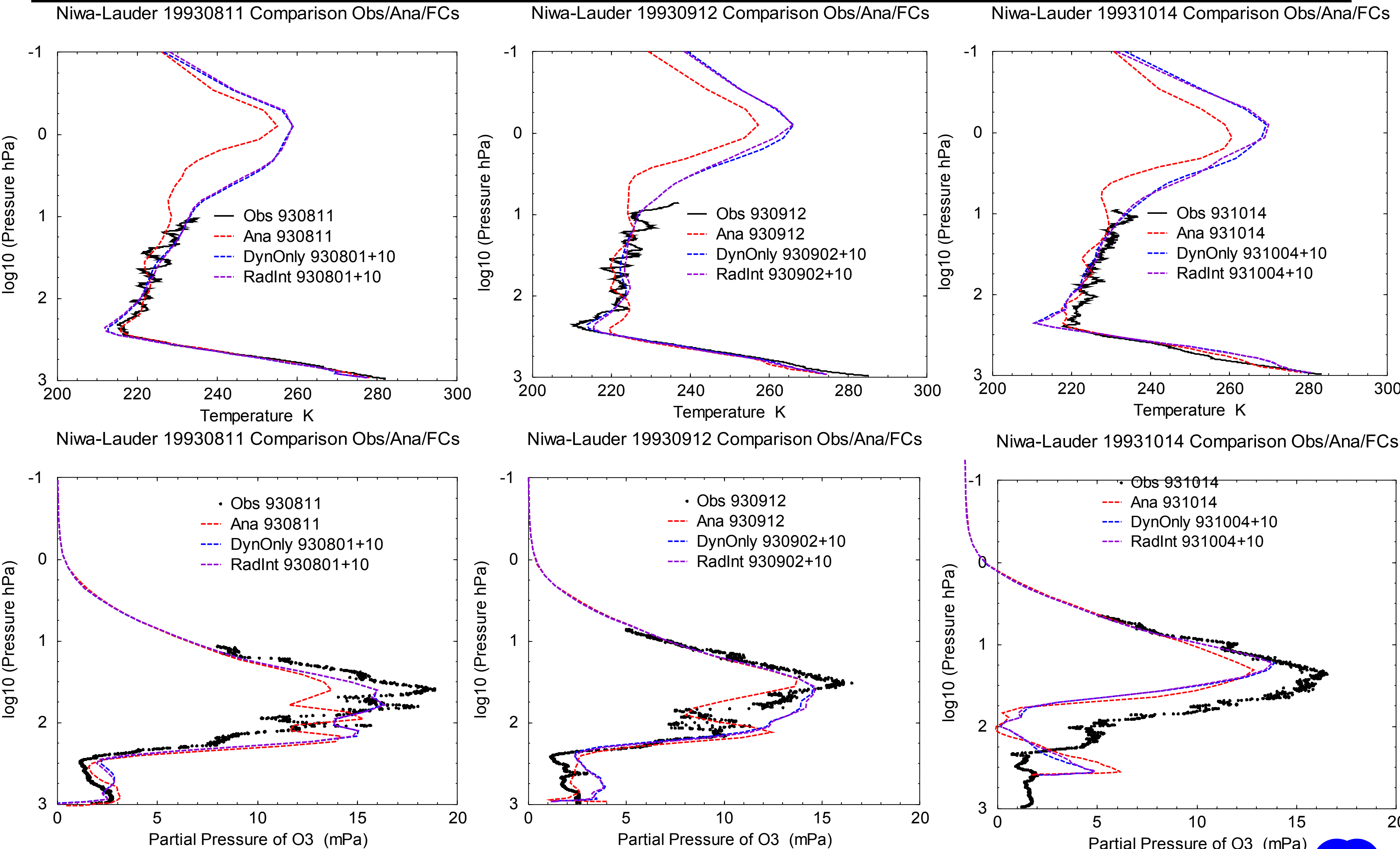






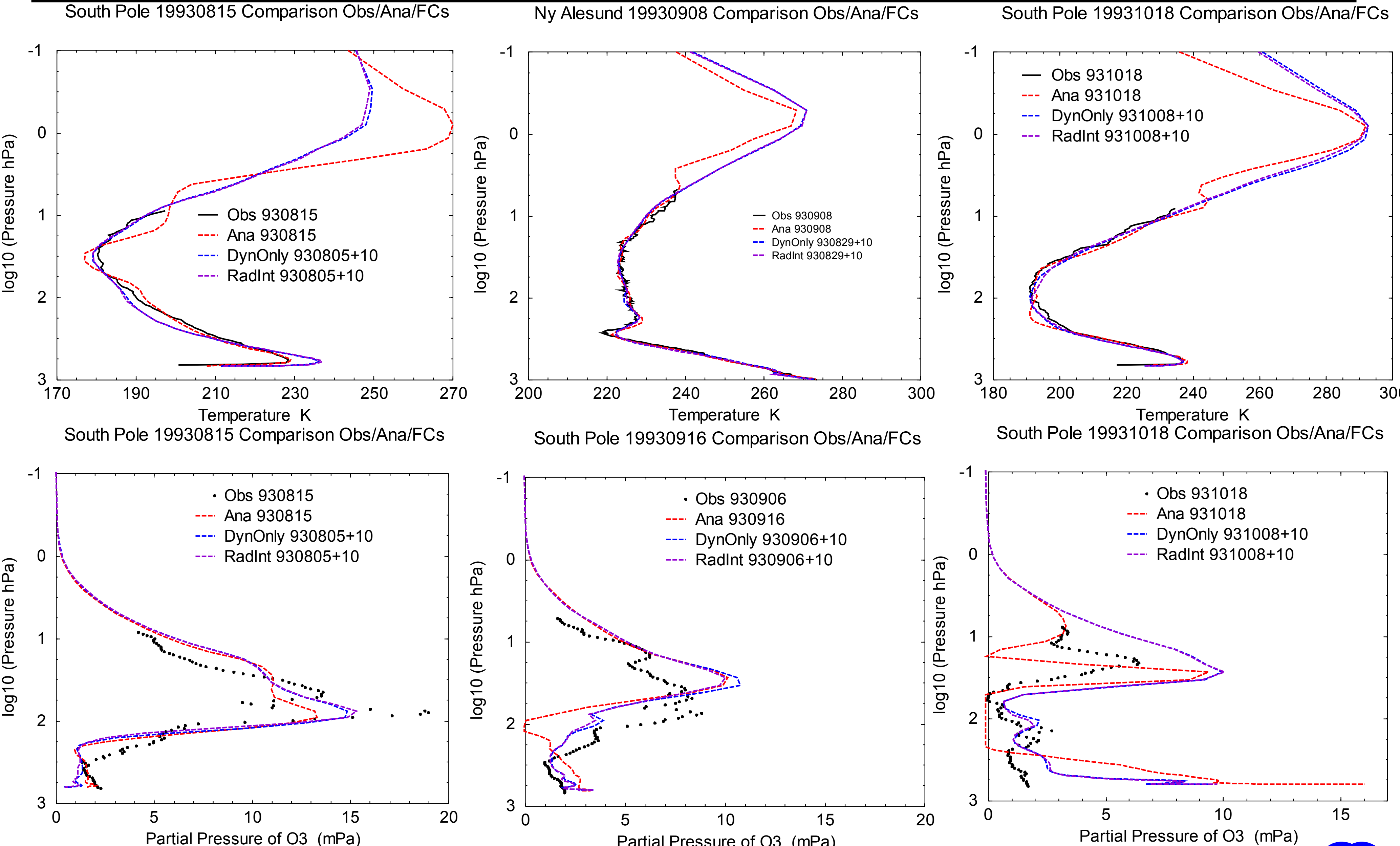


Comparison with T and O_3 profiles from ozonesondes: Niwa-Lauder: 45.04S 169.68E (NZ) August-October 1993

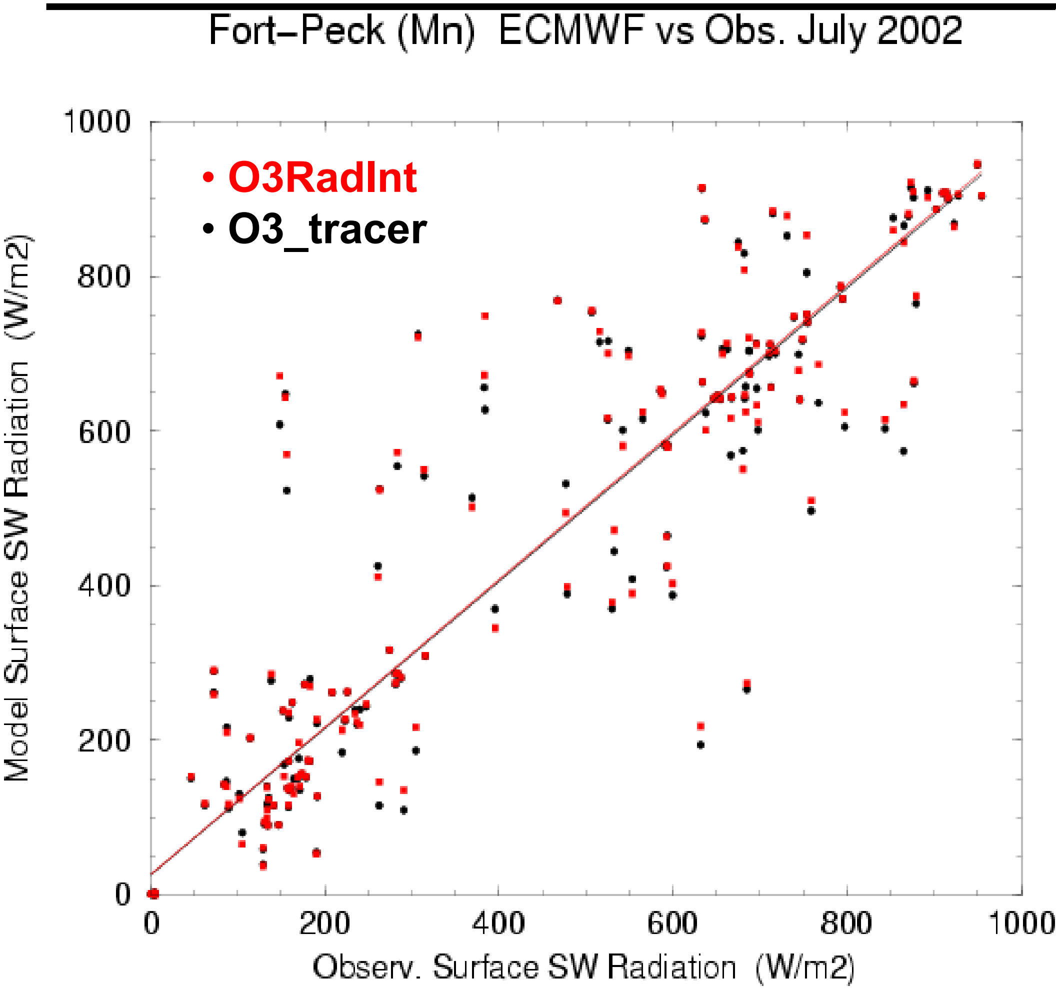


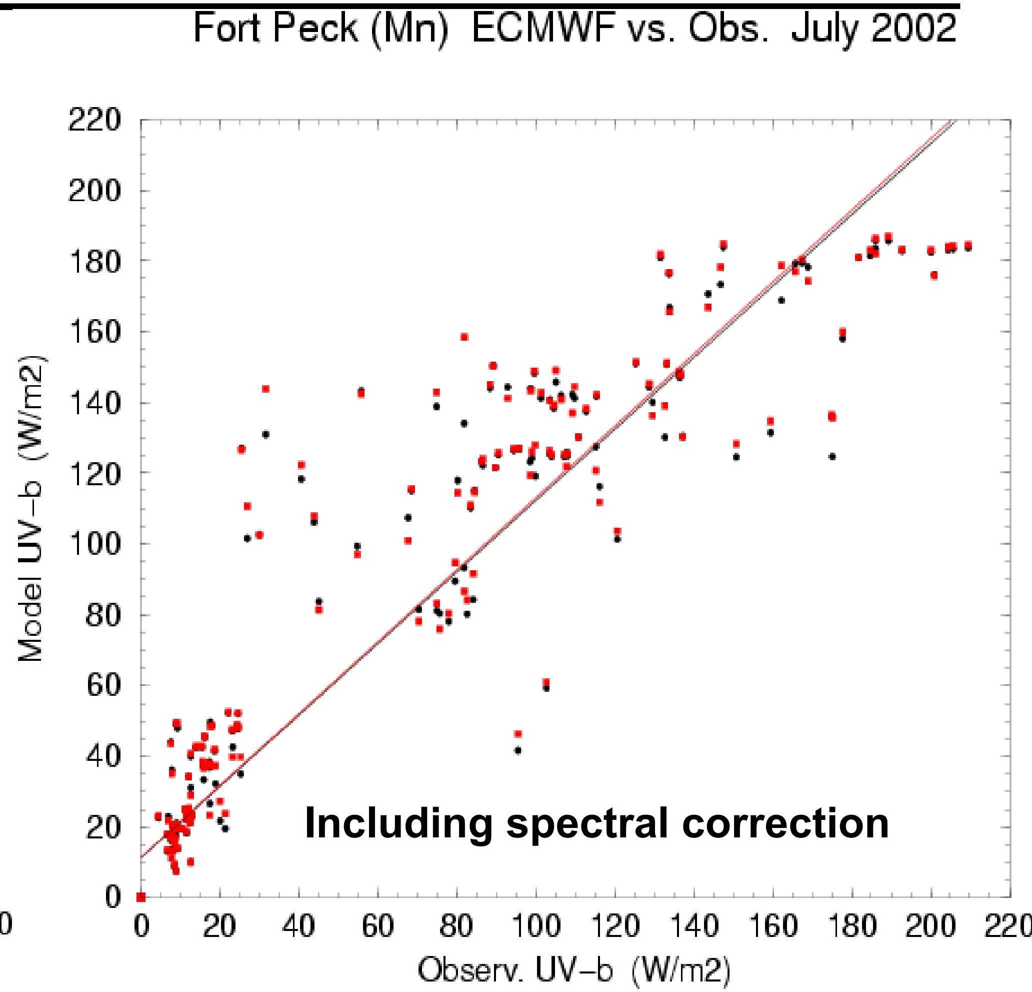
ECMWF

Comparison with T and O_3 profiles from ozonesondes: South Pole: 89.90S 0E August-October 1993



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 O_3/Radiation interactions, the cold temperature bias appearing above the tropical tropopause is linked to a reduced local concentration of O_3 w.r.t. the climatology. As expected, RT acts as a negative feedback but not powerful enough to compensate for the deficiencies in O_3 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.