Coupling global CTM to ECMWF's integrated forecast system for forecast and data assimilation within GEMS

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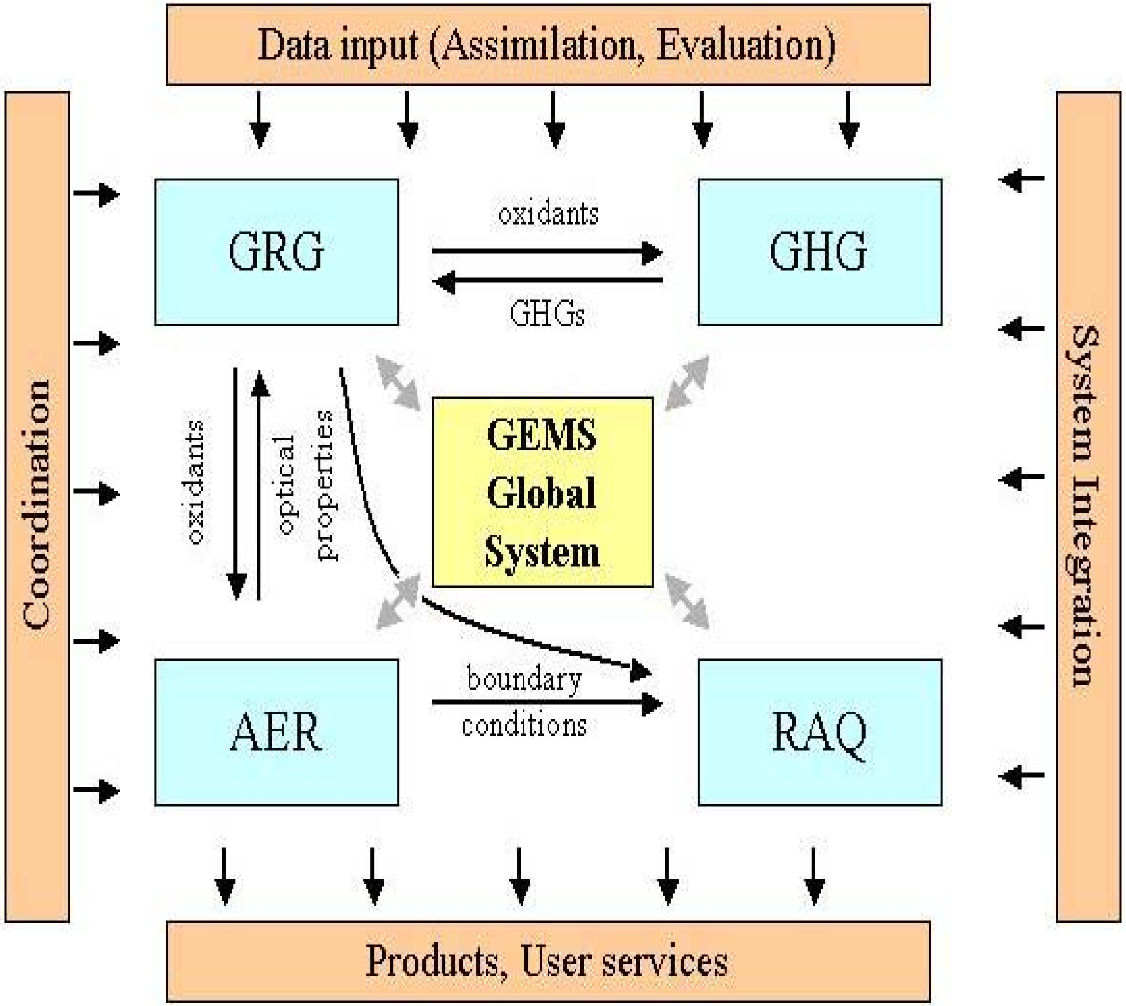
Outline

- Overview GEMS project
- The coupled system CTM-IFS
  - ➔ Design & Motivation
  - ➔ Scientific integrity
  - ➔ First results forecast
  - ➔ First results data assimilation
- Aerosol and NWP interaction at ECMWF
- Conclusion

Global and regional Earth-system (Atmosphere) Monitoring using Satellite and in-situ data (GEMS)

- FP7 , funded by EC and GMES, 31 Partners, 05/2005-01/2009
- GHG, AER, GRG and RAQ thematic subprojects
- Main deliverables
  - ➔Atmospheric composition re-analysis (2003-2007) by assimilating satellite data and validated by in-situ data
  - ➔Regional air quality forecasts
  - ➔Green house Gas flux inversions
- Global Production System centered at ECMWF

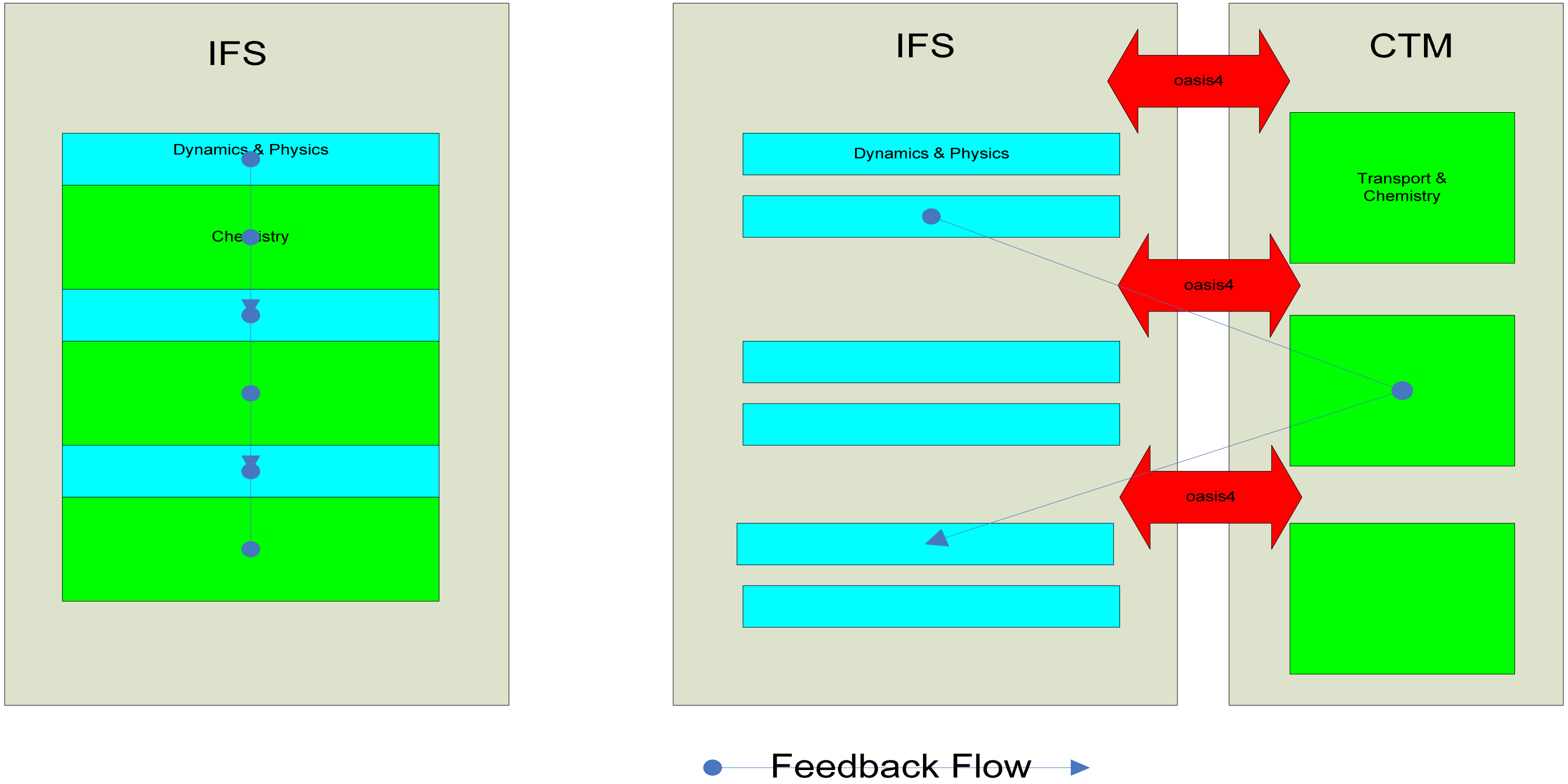
GEMS production system



Global reactive gases approach (GRG)

- Assimilate species in IFS using ECMWF 4D-VAR
- Integrating full chemistry seemed not affordable
- Include NO_x, SO_2, O_3, CO and HCHO (observed) in IFS transport and assimilation
- Introduce source and sinks by coupling with Chemical Transport Models (CTM) using the same emissions
  - ➔ MOZART (MPI-Hamburg) – 106 species
  - ➔ TM5 (KNMI) – CBM4: 50 species
  - ➔ Mocage (Meteo France) – REPROBUS: 120 species
- Provide CTM tendencies (chemistry, emissions & deposition) to the IFS

Integrated system vs. coupled system
"online" vs. "offline"



Integrated System
Feedback: fast
Flexibility: low

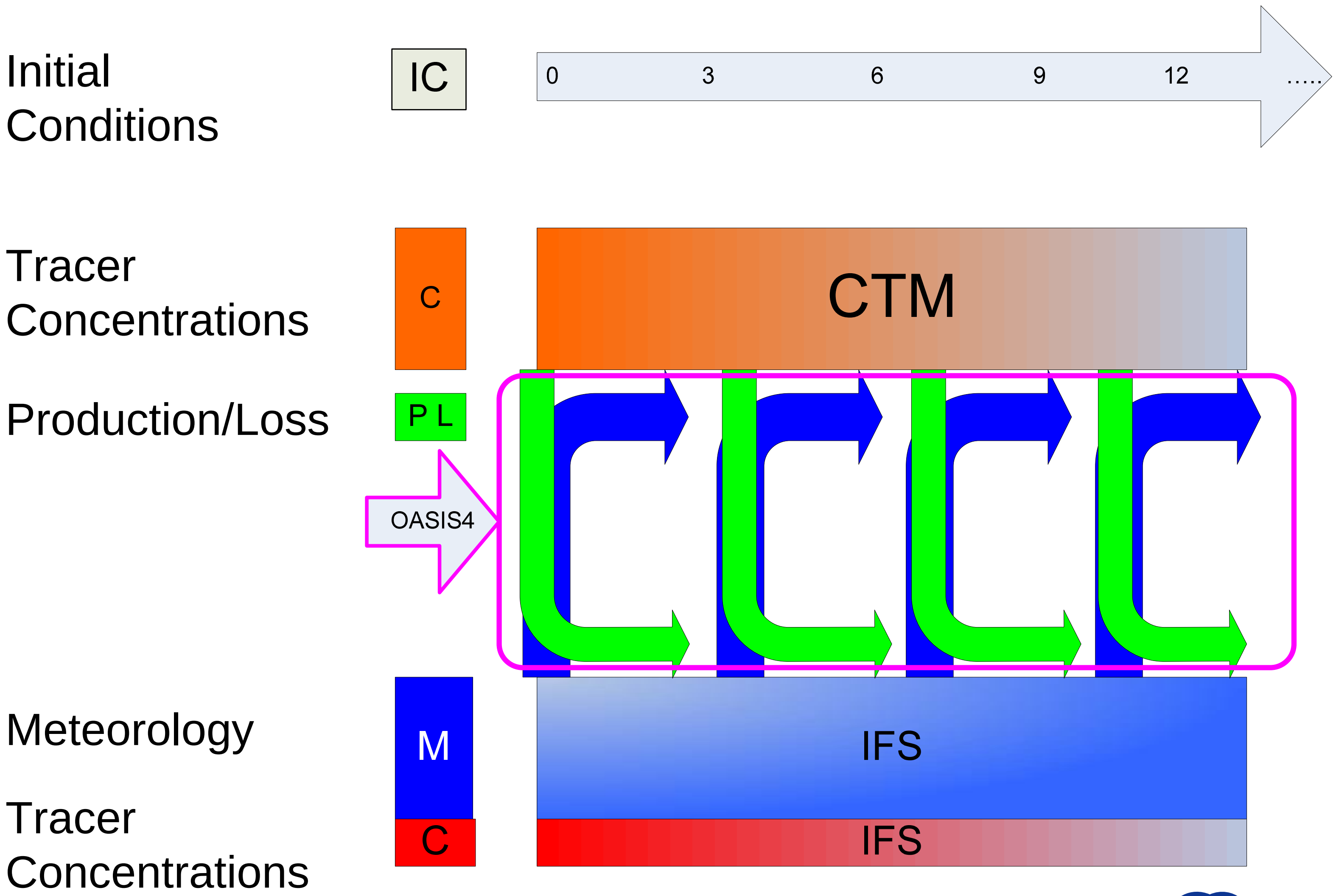
Coupled System
Feedback: slow
Flexibility: high

Integrated *vs.* coupled system

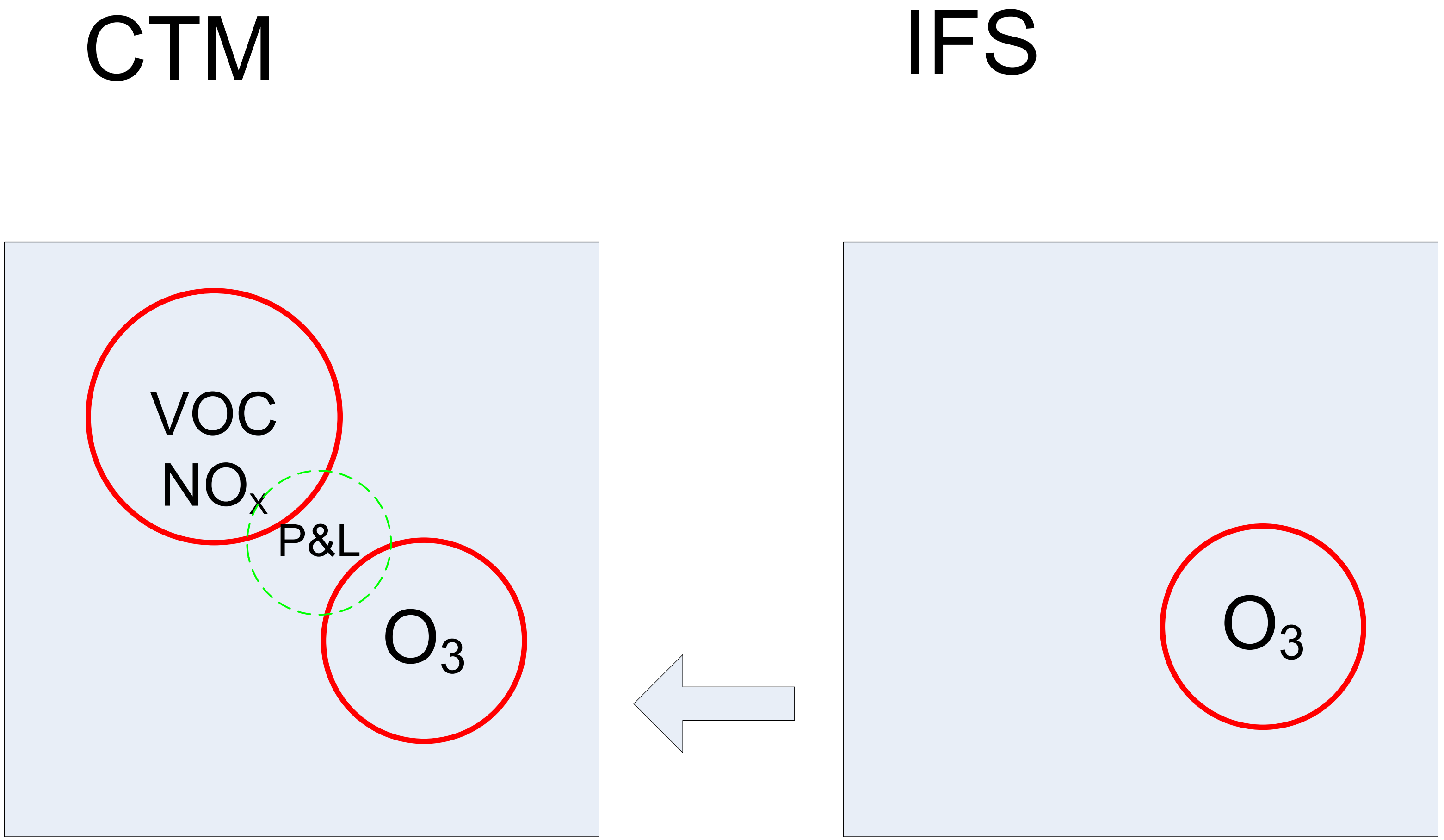
- **Integrated system**
  - ➔ **Approach in GEMS GHG and AER**
  - ➔ **Include subroutines describing the processes**
  - ➔ **Consistent with the IFS**
  - ➔ **Better performance**
  - ➔ **Increases the complexity of an already complex system**

- **Coupled system CTM - IFS**
  - ➔ **Approach in GRG, parallel coupling using OASIS4**
  - ➔ **Provide source sink tendency from CTM**
  - ➔ **Consistency problems**
  - ➔ **Latency problems**
  - ➔ **More flexibility and independence**

Coupling in Forecast mode



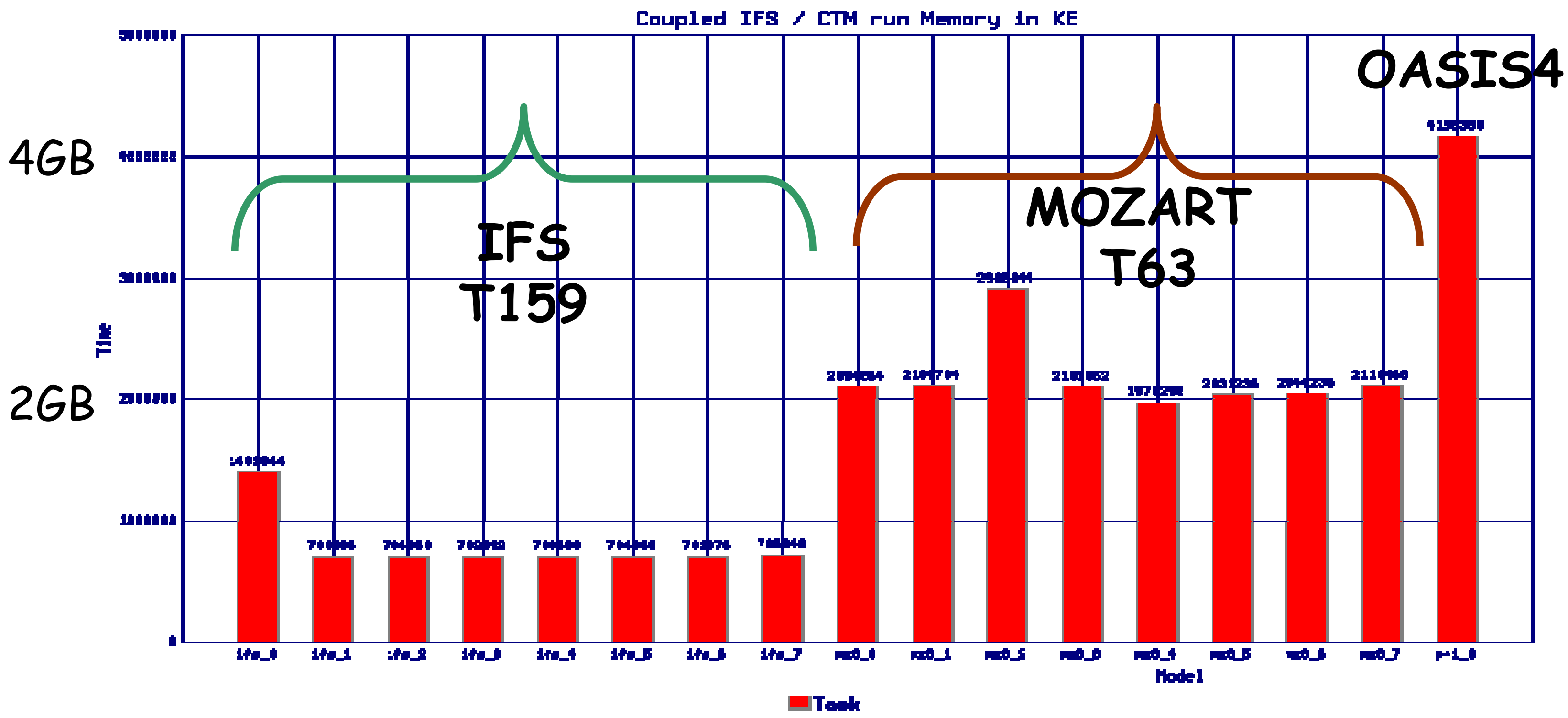
"Dislocation" problem



Coupler OASIS4

- Efficient data exchange between models because of direct MPI communication without global gathering of data
- Interpolation tool (black) box
- Well-defined interface for model interoperability
- Easy to implement in code
- Control overhead very big
- Memory consumption high
- **OASIS4 is work in progress**
  - ➔ No full functionality yet (conservative interpolation, global search)
  - ➔ *OASIS4 people very helpful*

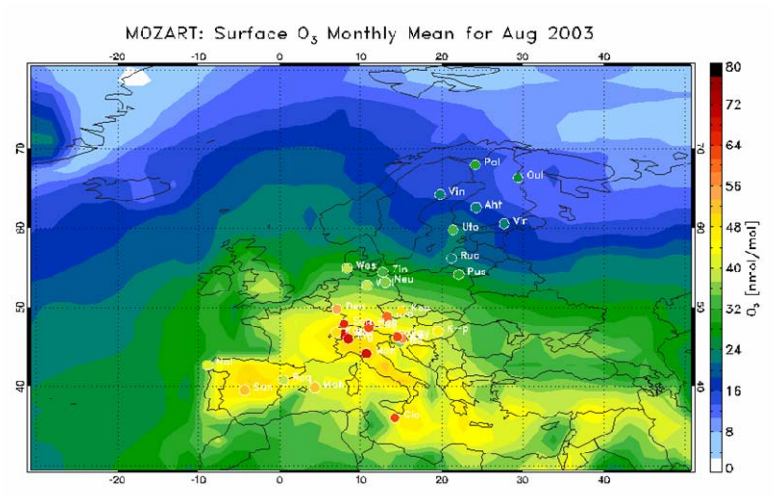
Maximum memory consumption per MPI tasks



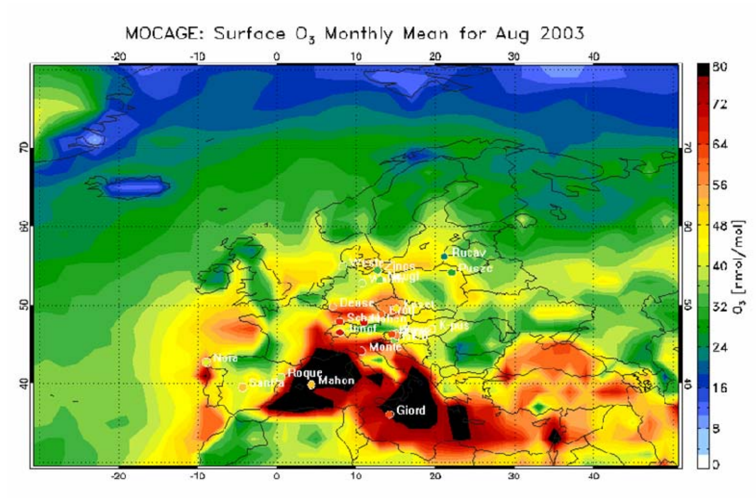
IFS 6.3 GB
MOZART 18.4 GB
OASIS4 4.1 GB

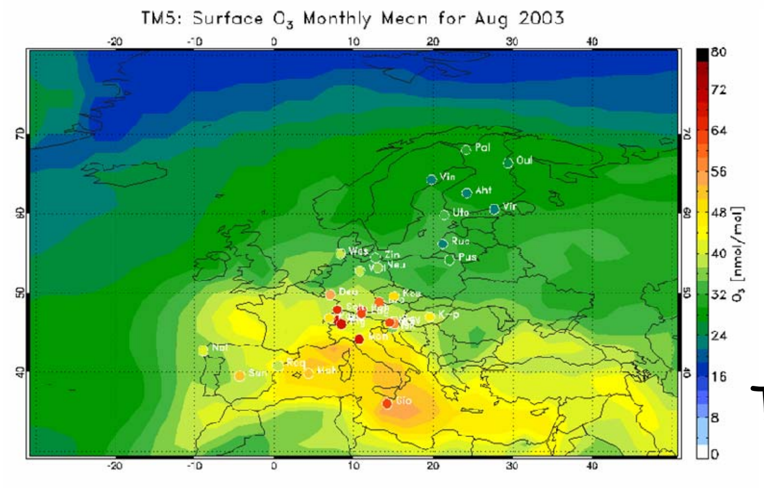
Variability of CTMs: Ozone - heat wave August 2003

MOZART



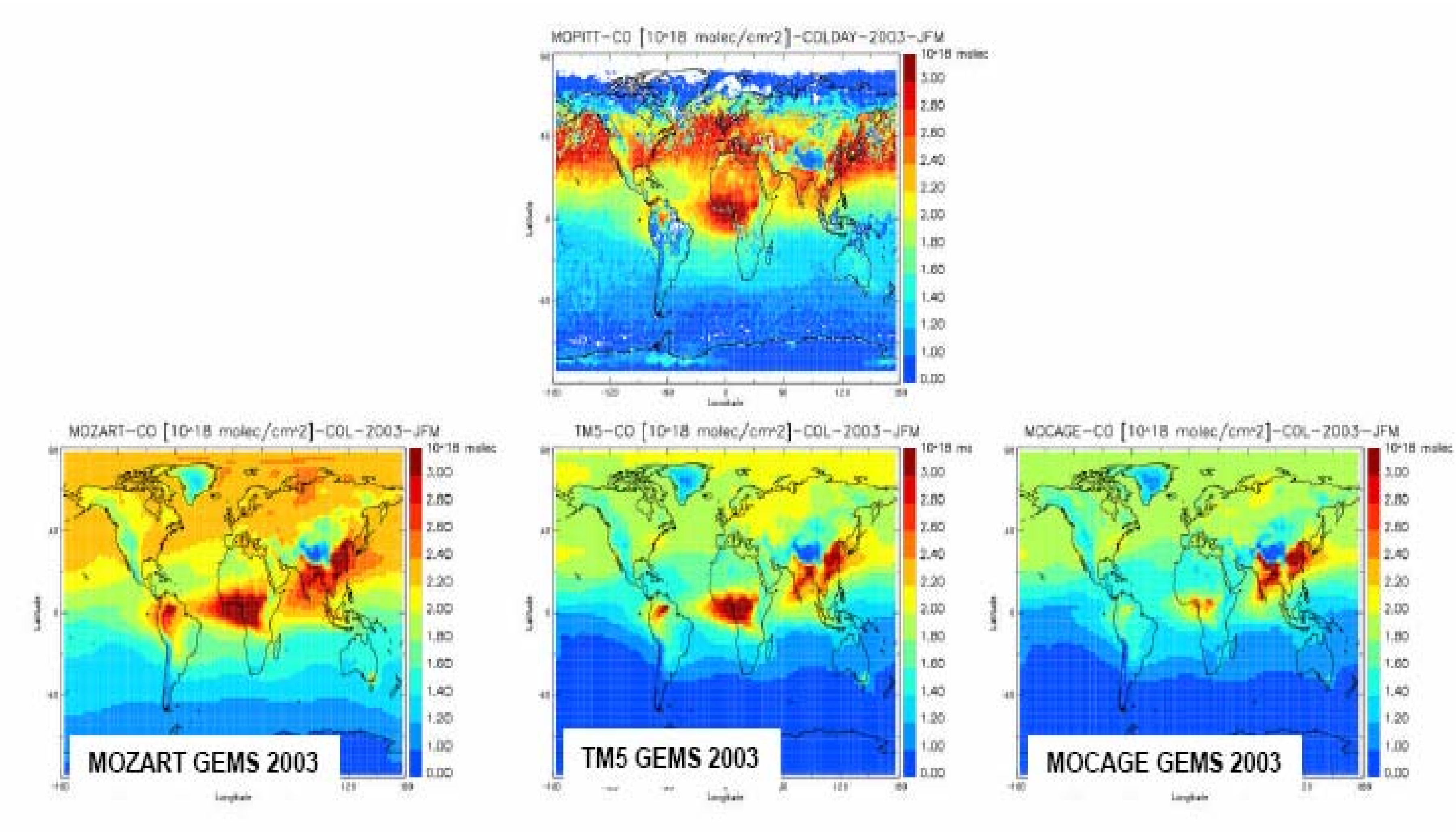
MOCAGE





TM5

Variability of Models:
CO total columns 2003



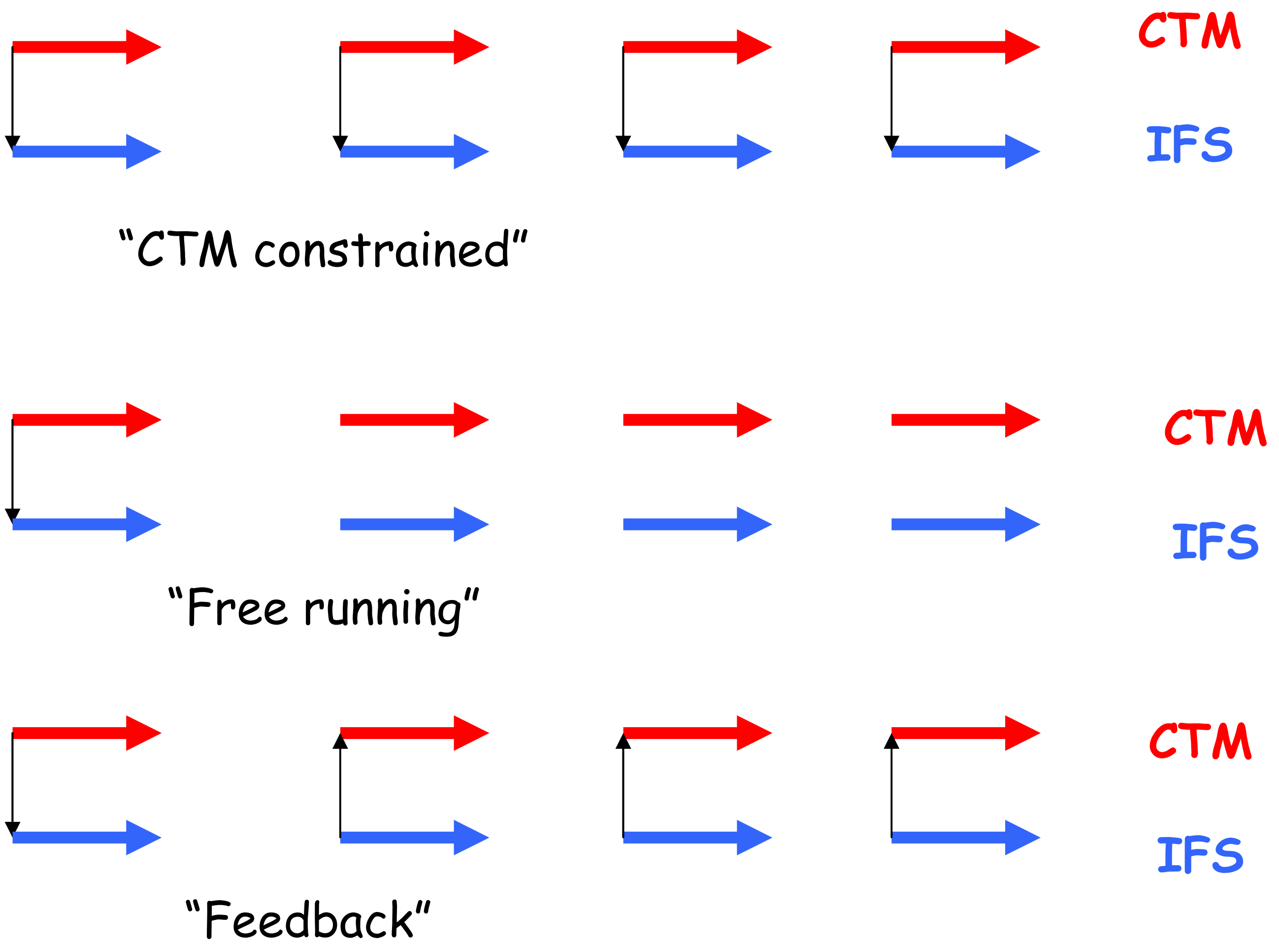
CTM implementation at ECMWF status

	MOZART	**TM5**	**MOCAGE**
Coupled in hpc environment	yes	yes	yes
prepIFS launch of FC and AN	yes	yes	yes
Stable configuration mpi/omp	**8/4, 8/8, 16/8**	**8/1**	**1/24**
IC & Tendency output GRG + NO_x	Yes	yes	yes
Feedback IFS -> CTM	CO	no	no
Extra met data from file needed	no	yes	yes
Current run time 24h FC	**20, 13, 9 min**	**37 min**	**188 min**
Accomplished runs	6 month 48hFC 15 days AN	24h FC	2*24h FC

Standard Setup of GRG coupled system

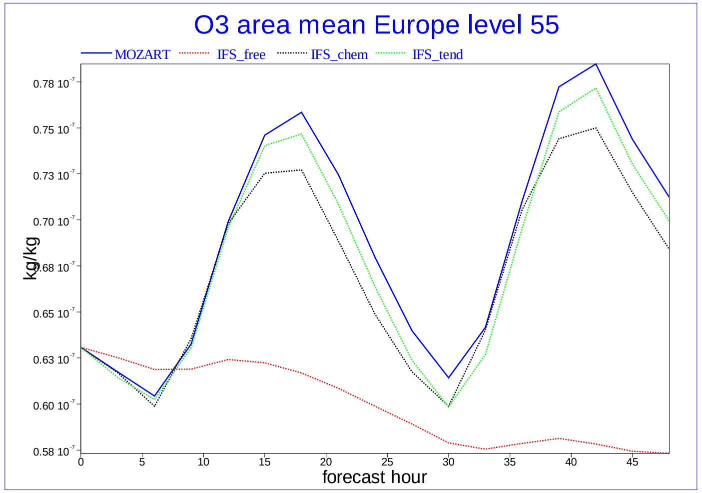
- IFS in T 159 / 60 Layers / TSTEP= 1800s
- MOZART in T 63 / 60 layers / TSTEP= 900s
- Coupling frequency 3600 s
- No vertical interpolation
- IFS to CTM:
  - ➔ 3D T, u ,v, q, taux, tauy, shlflx, qflx
  - ➔ CO tracer option
- CTM to IFS:
  - ➔ concentrations (CO, NOx, O3, HCHO)
  - ➔ tendencies as 3D totals or 3D Chemistry + 2D fluxes

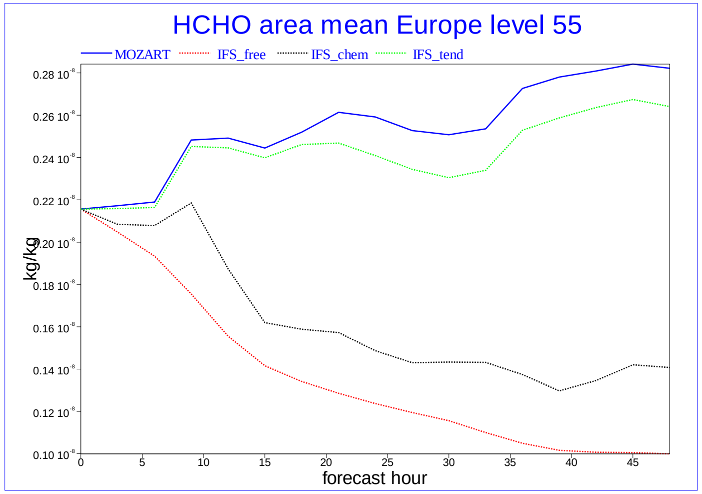
Modes of coupling – sequence of forecasts

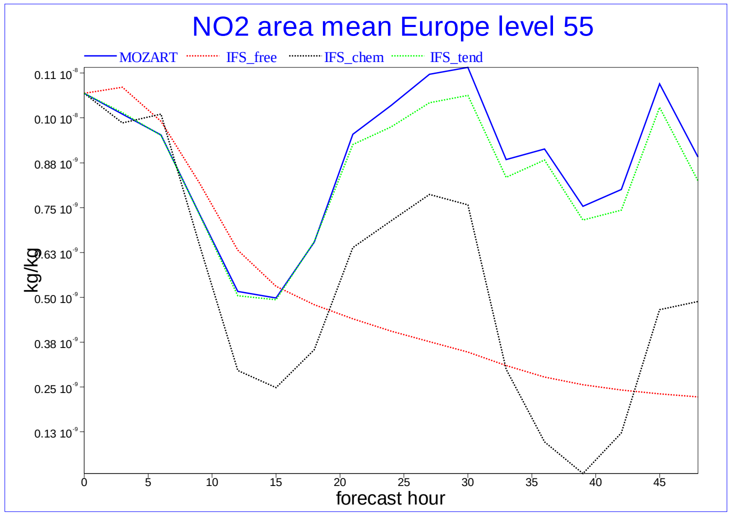


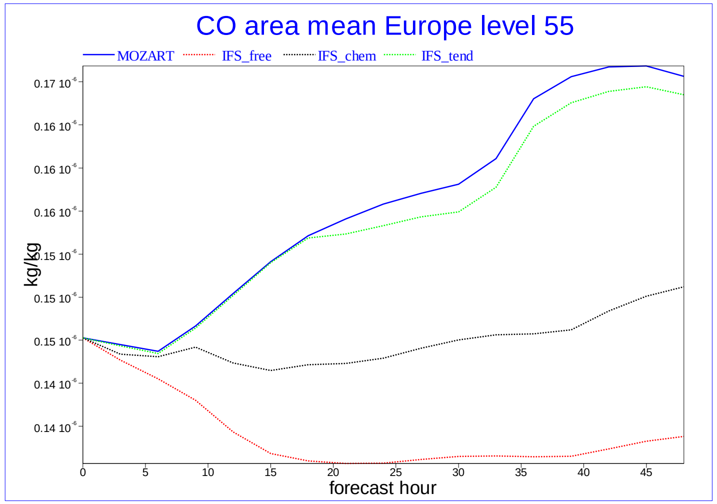
ECMWF

Can IFS-CTM imitate the CTM ?

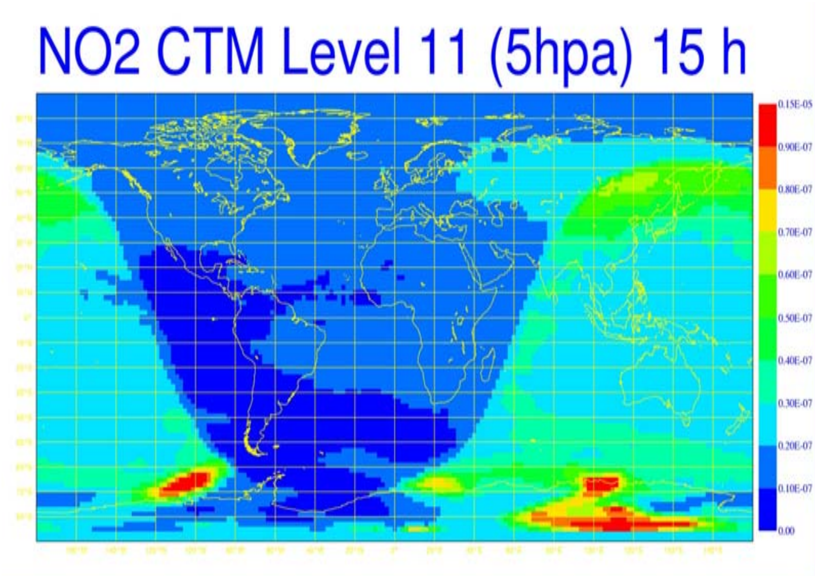


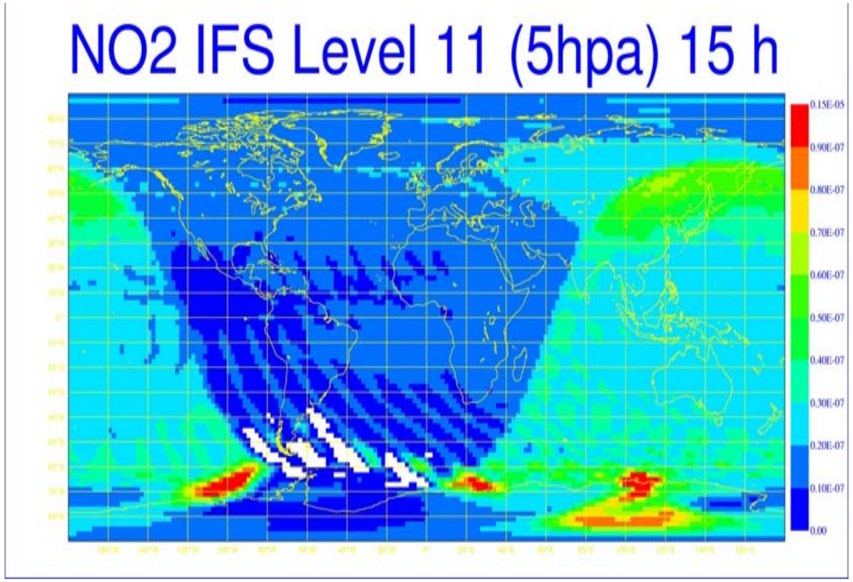






NO2 at 5 hPa from MOZART CTM and IFS



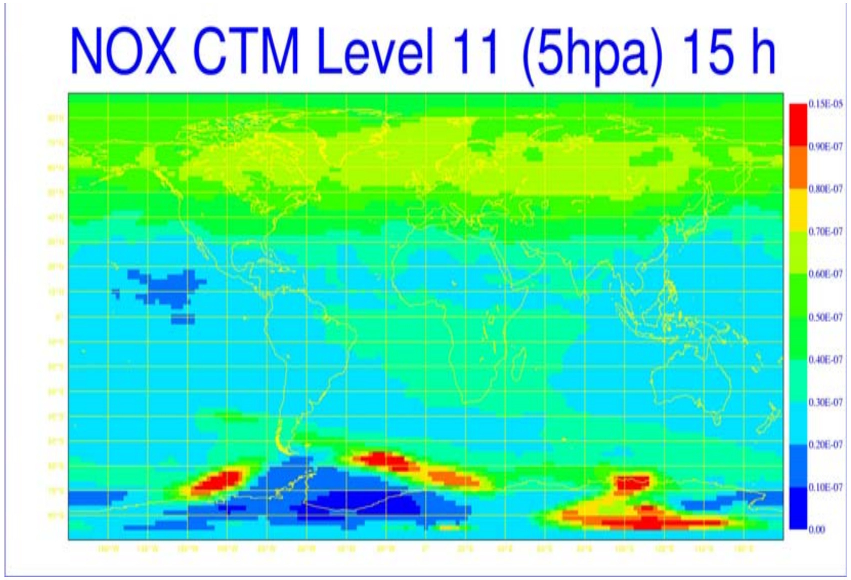


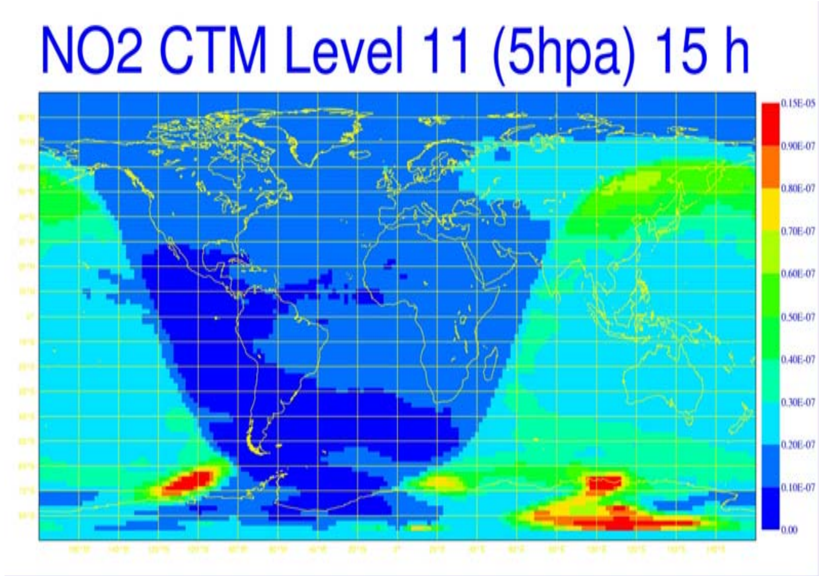
Fast NO_2/NO interconversion in stratosphere and mesosphere can not be succesfully modeled with the coupling approach.

-> Use NO_x as IFS tracer and an interconversion operator as part of the observation operator for NO_2

ECMWF

NO2/NOx interconversion operator



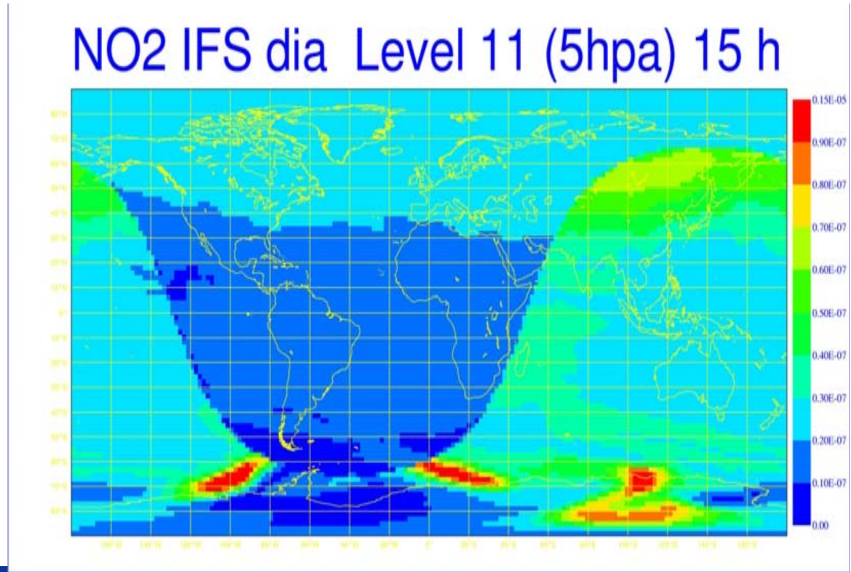


Inter-conversion operator:

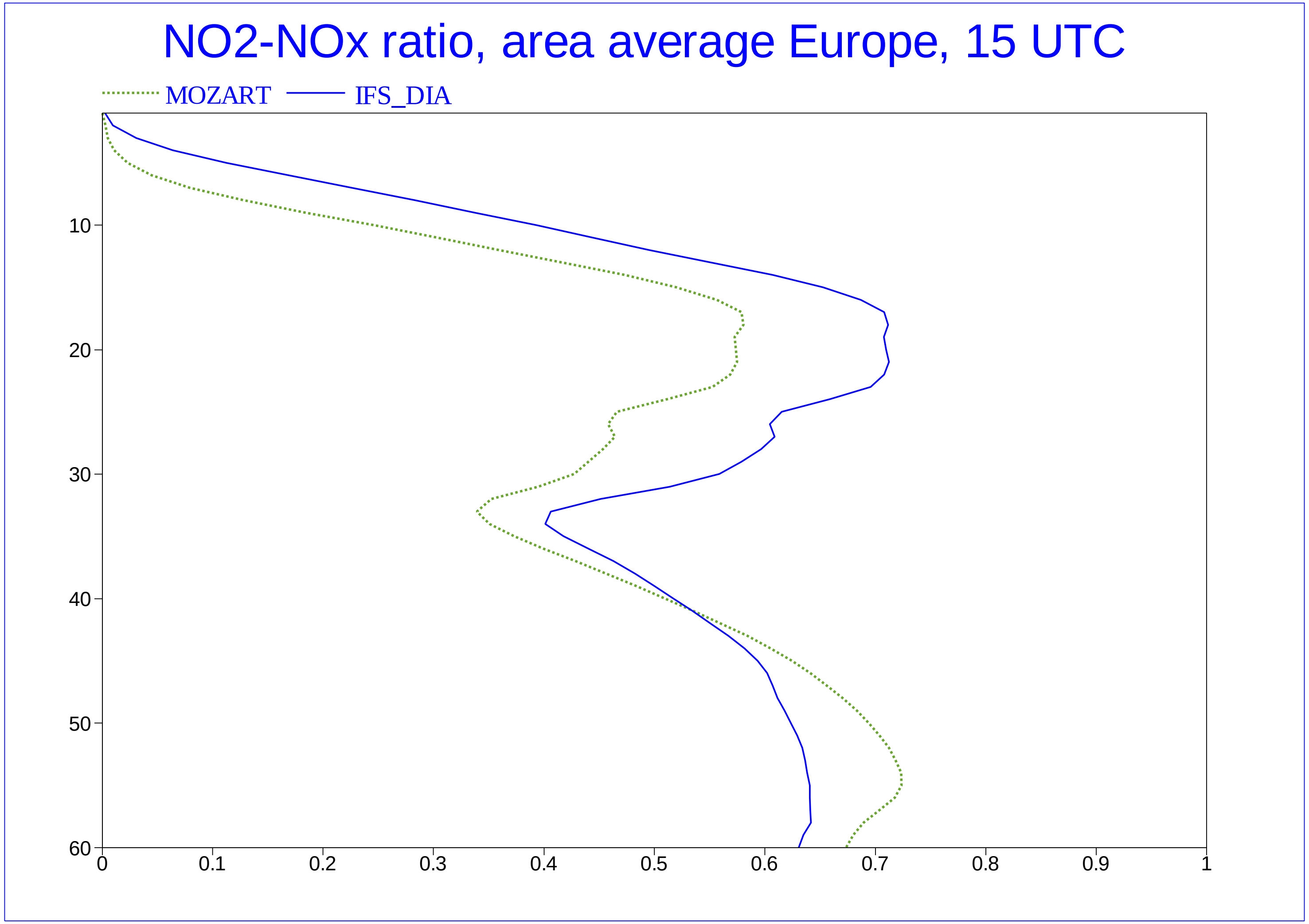
$$\frac{[NO_2]}{[NOx]} = \frac{k[O_3]}{JNO_2 + k[O_3]}$$

depends on:

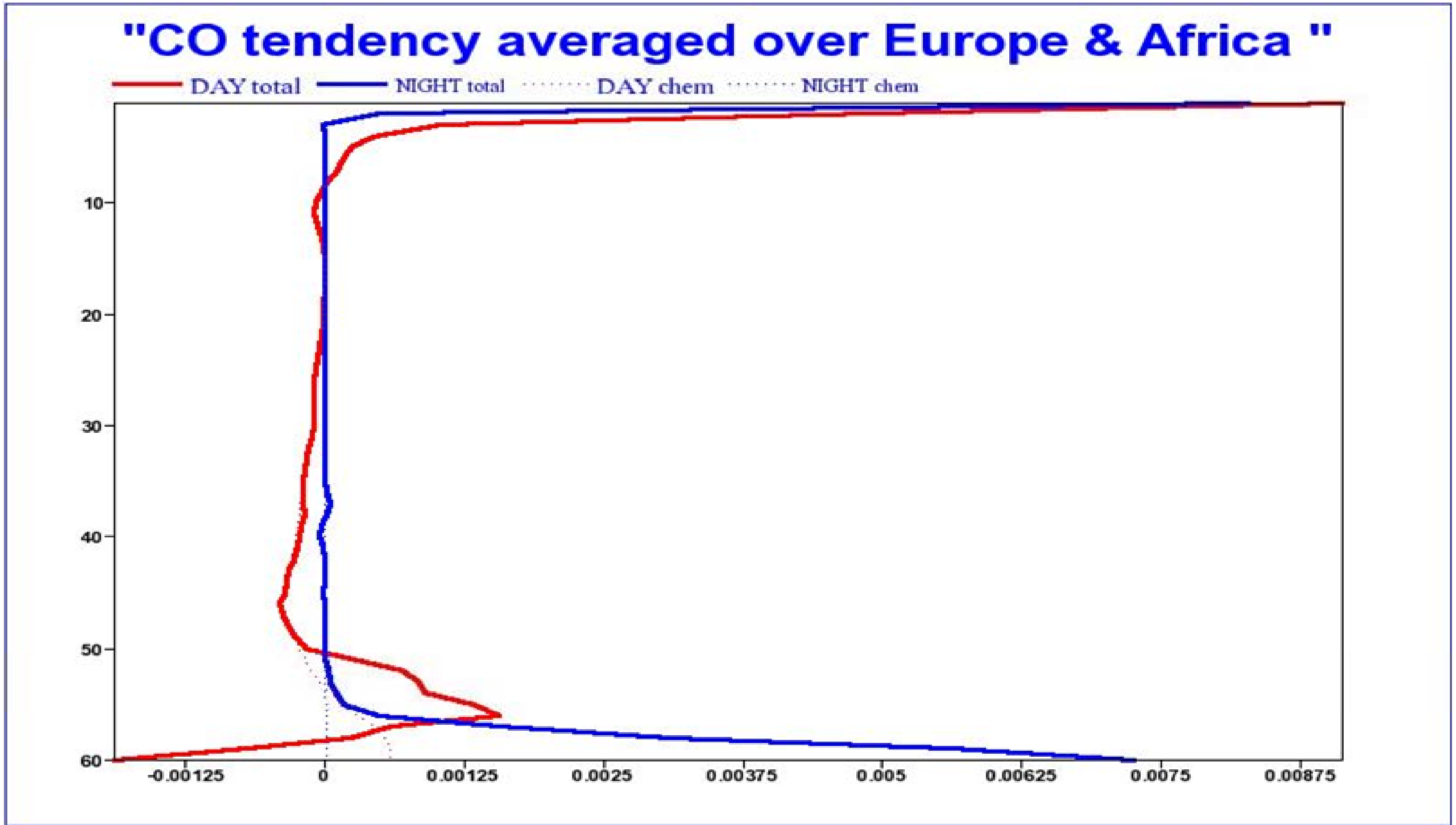
- Solar zenith angle
- O_3 concentration
- Slant O_3 column
- Temperature



Vertical profile NO2-NOx ratio MOZART vs. diagnostic IFS



CO tendency profile night vs. day



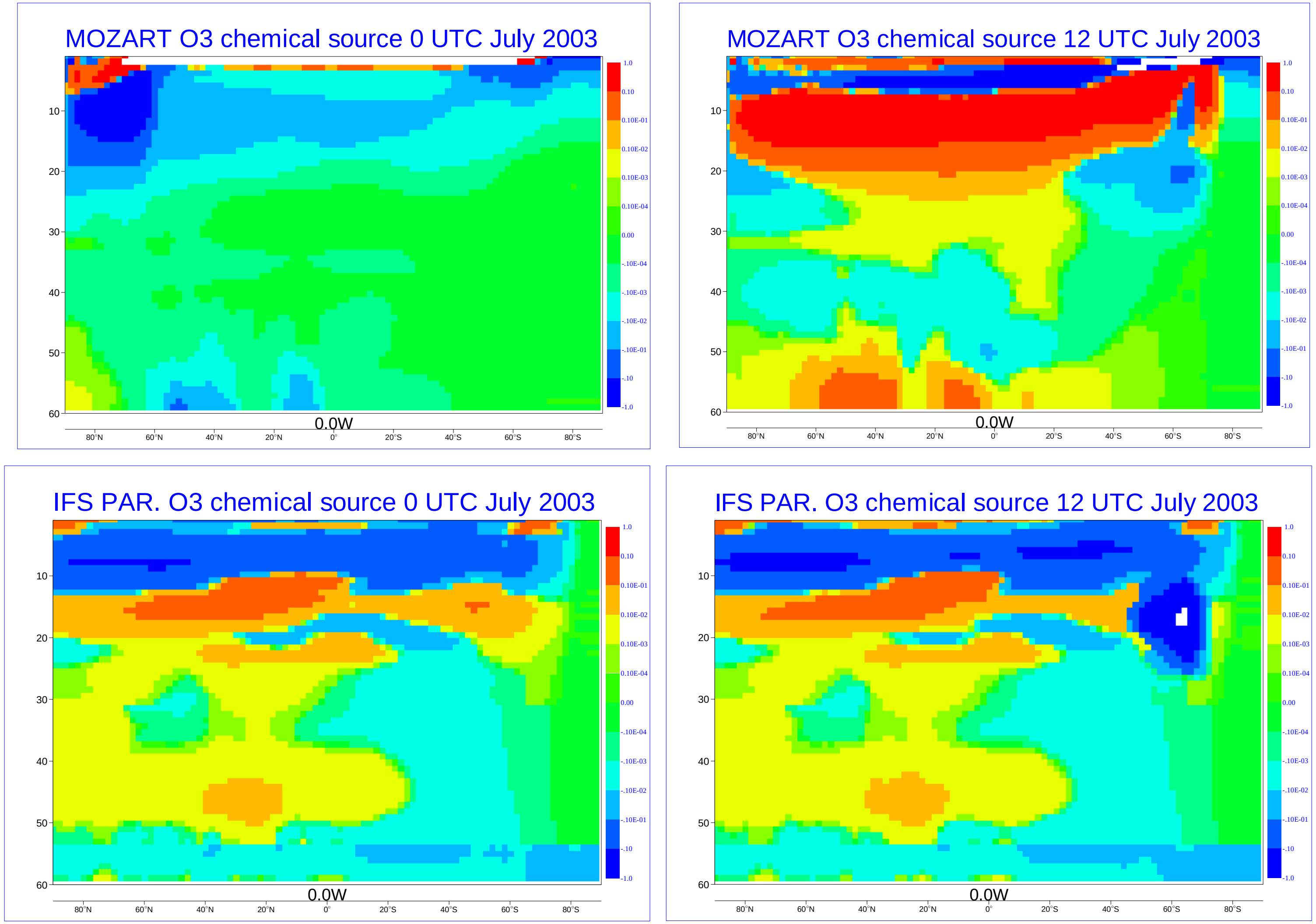
Emission& Diffusion + Chemistry

Averaged O3 MOZART chemistry tendencies *vs.* Cariole parameterisation

0 UTC | 12 UTC

MOZART

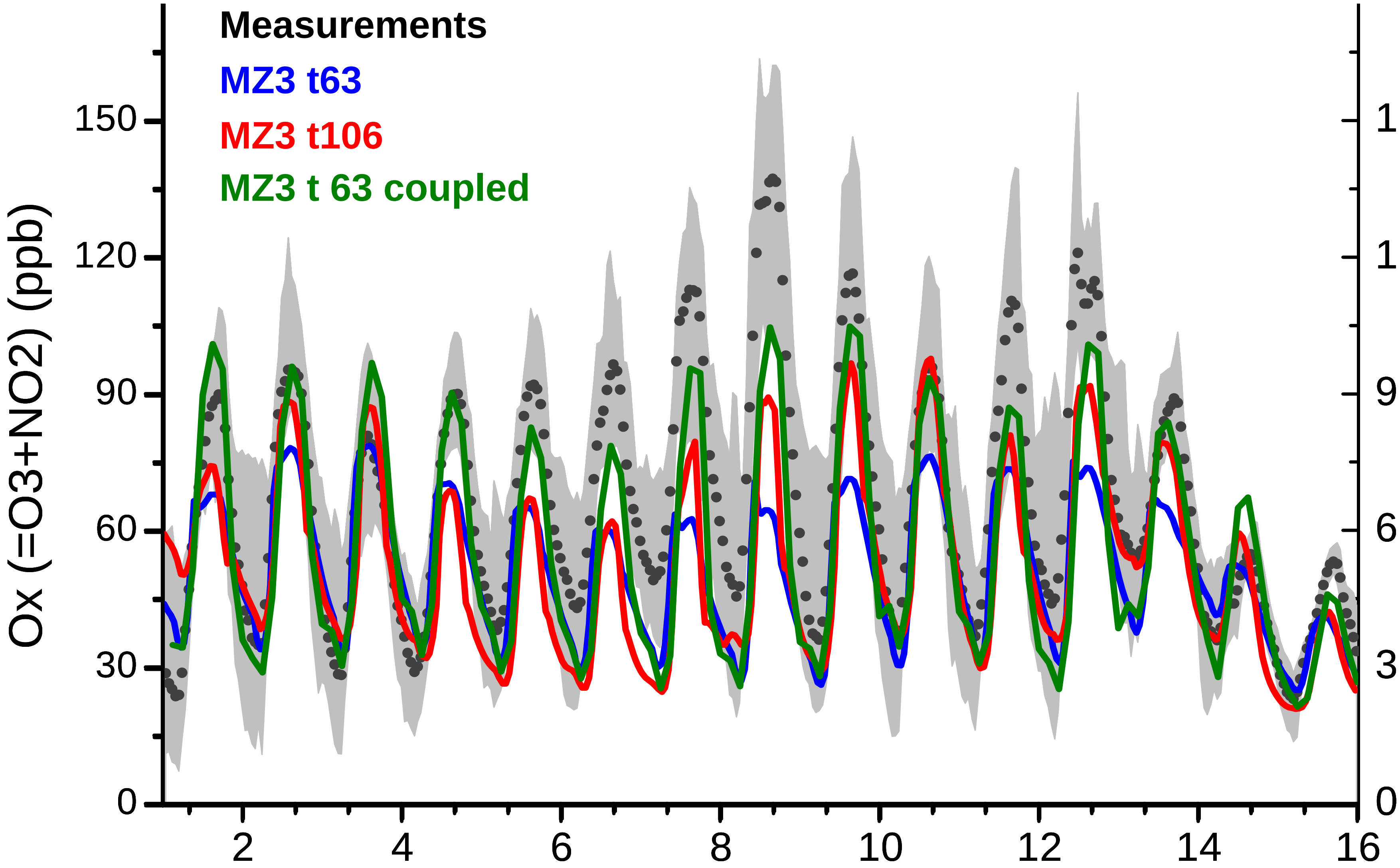
Coriole



Benefit of coupling for CTM simulation ?

- Coupled run *vs.* stand-alone runs
  - ➔1 hourly *vs.* 6 hourly
  - ➔Forecast (T159) from Analysis *vs.* time interpolated re-analysis (no forward interpolation)
  - ➔Balanced fields vs. analyzed fields
- IFS transport *vs.* vertical transport
  - ➔Tracer in IFS allow comparison especially for vertical transport
- IFS cloud *vs.* CTM cloud
  - ➔Are very different although q is the same

Ox MOZART North-Rhine Westphalia 08/2003

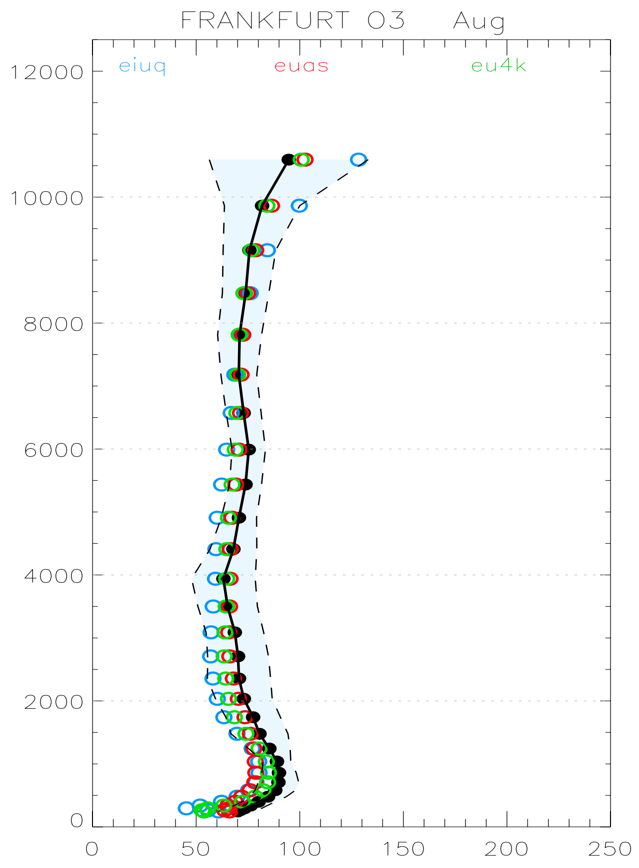


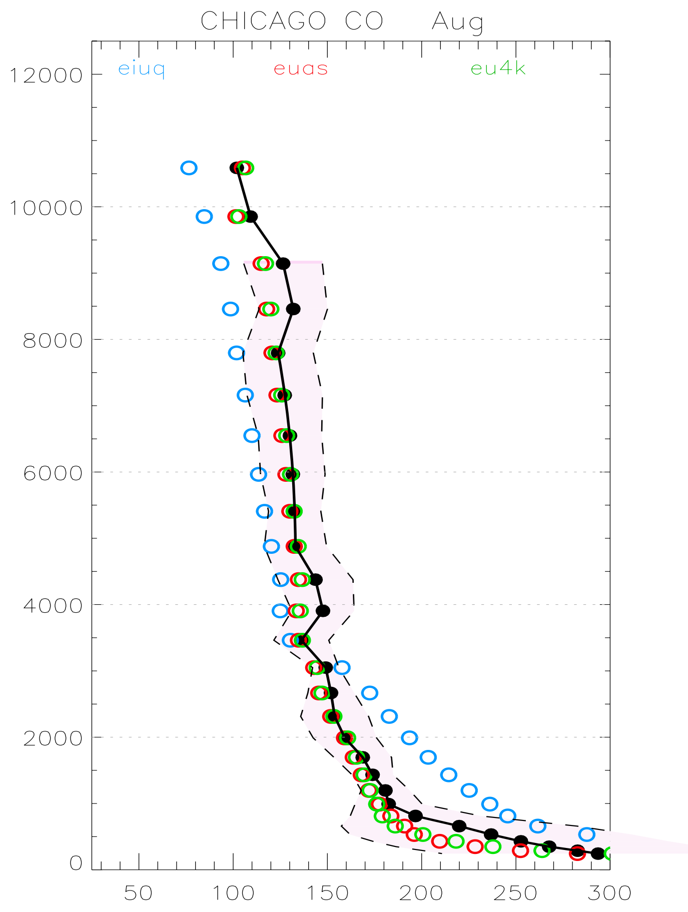
Olaf Stein MPI-HH

ECMWF

IFS vs. MOZART vertical transport

euiq vertical transport à la MOZART
eu4k IFS convection & MOZART difussion
euas IFS convection and diffusion

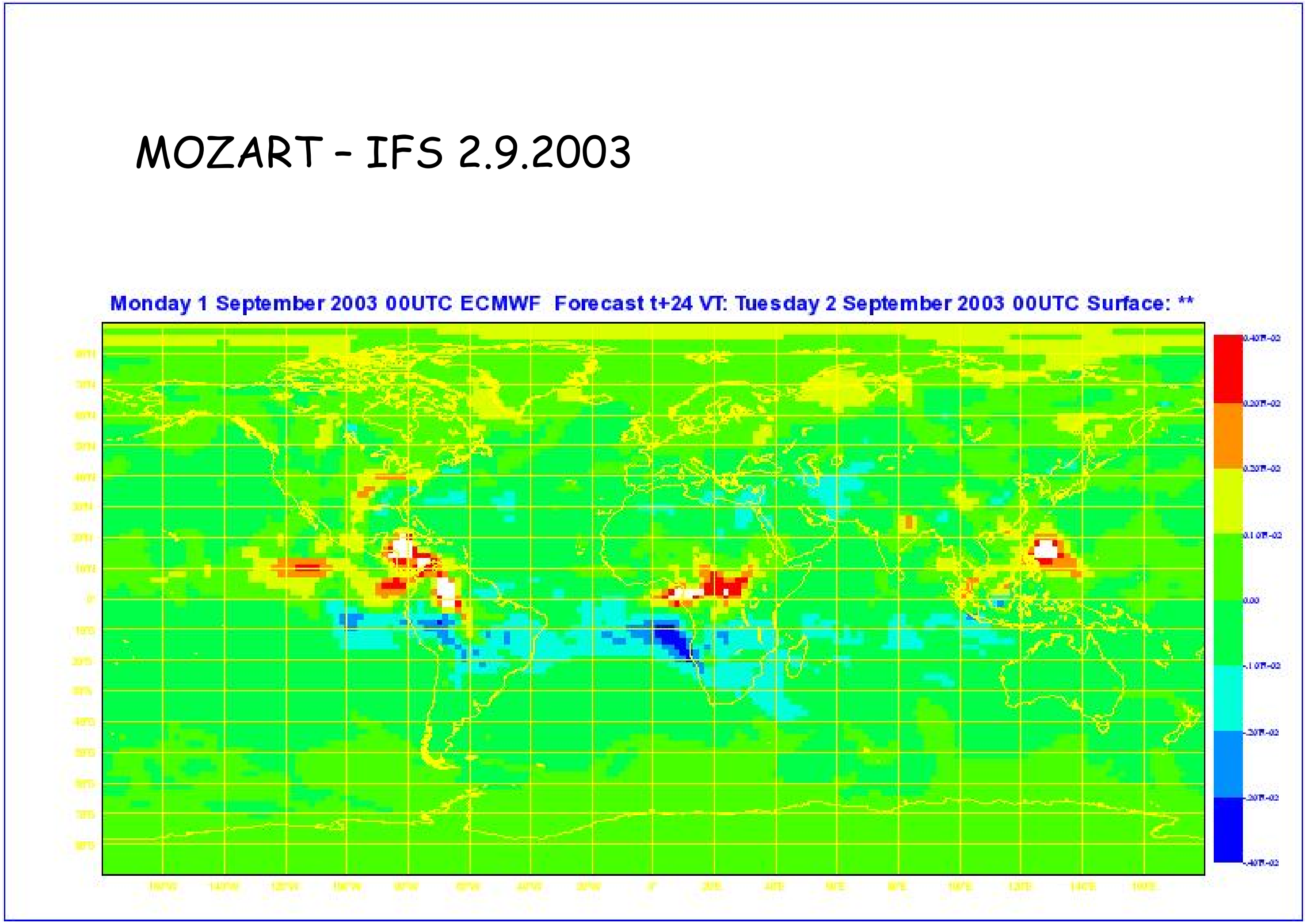




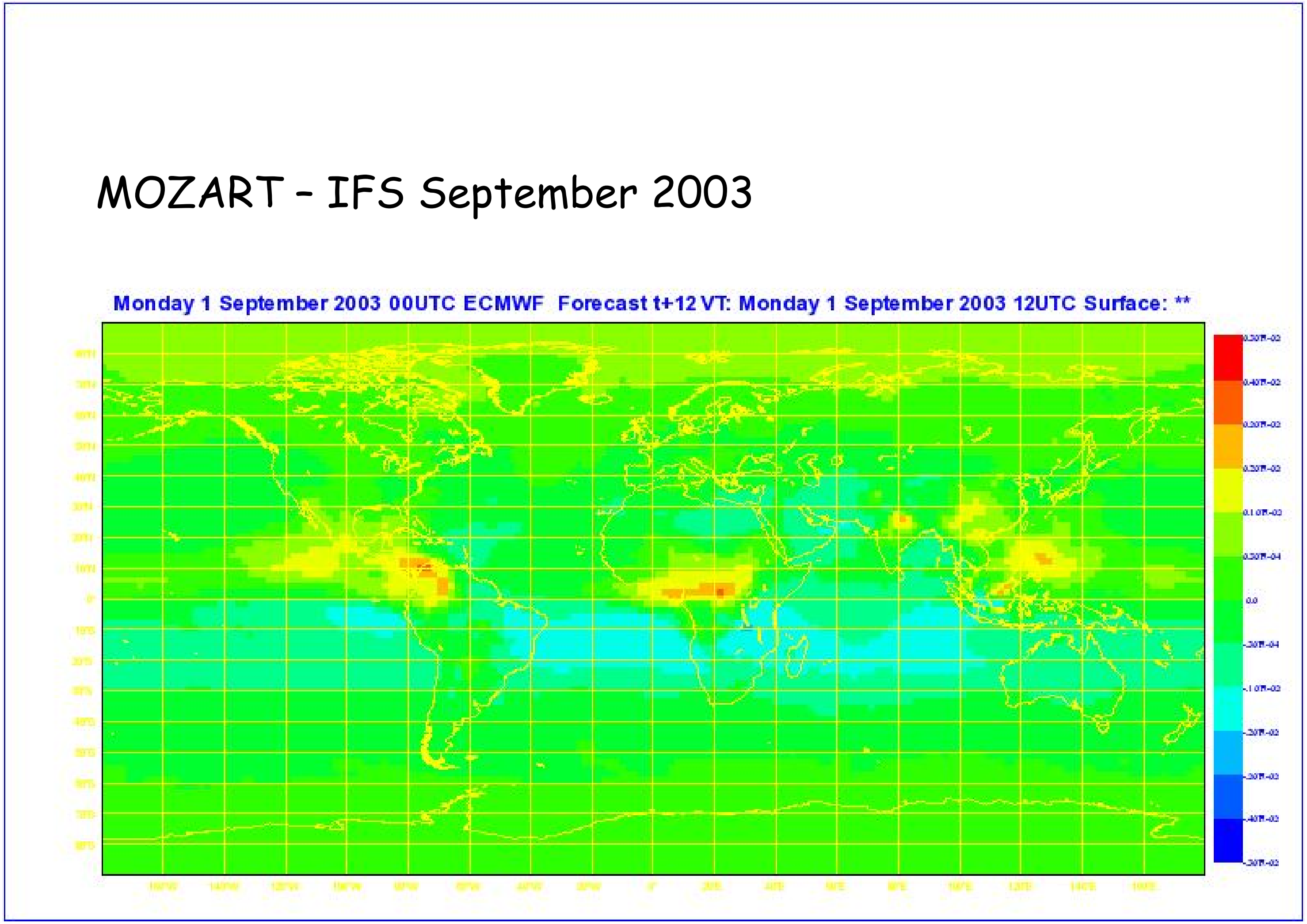
Carlos Ordonez

ECMWF

IFS vs. MOZART vertical transport



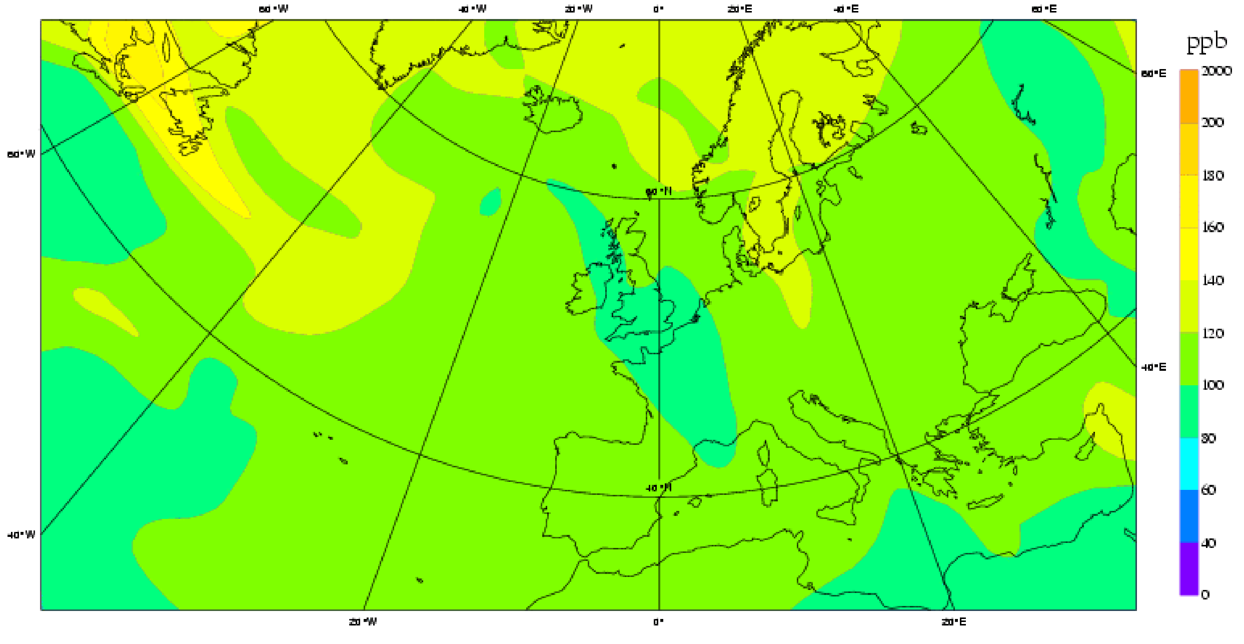
IFS vs. MOZART vertical transport



Experimental NRT Forecasts CO and O3

- http://www.ecmwf.int/products/forecasts/d/inspect/catalog/research/gems/grg/realtime/

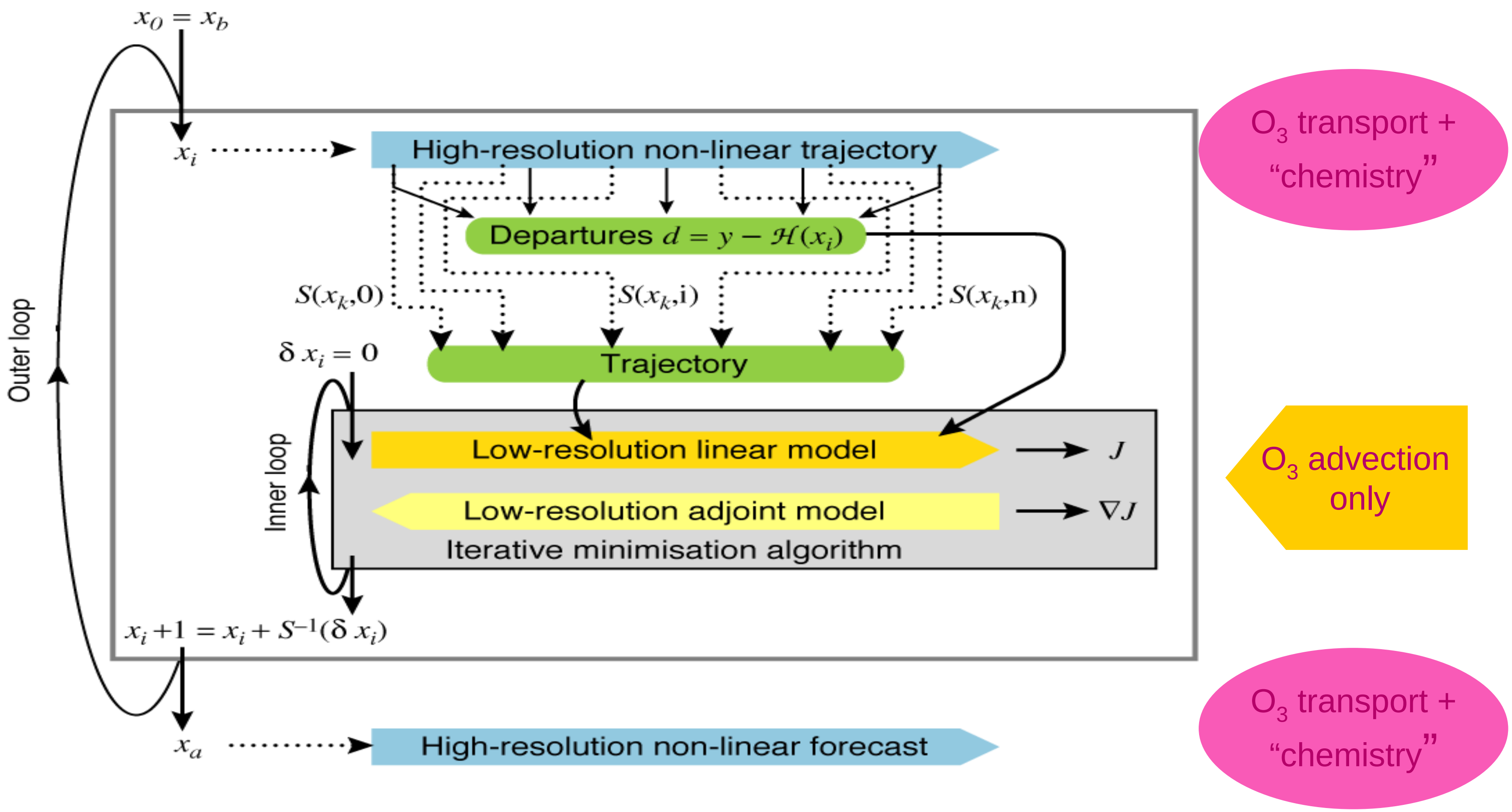
Thursday 17 May 2007 00UTC ©ECMWF Forecast t+006 VT: Thursday 17 May 2007 06UTC
500 hPa Carbon monoxide



Coupling in Data assimilation mode
(Antje Dethof)

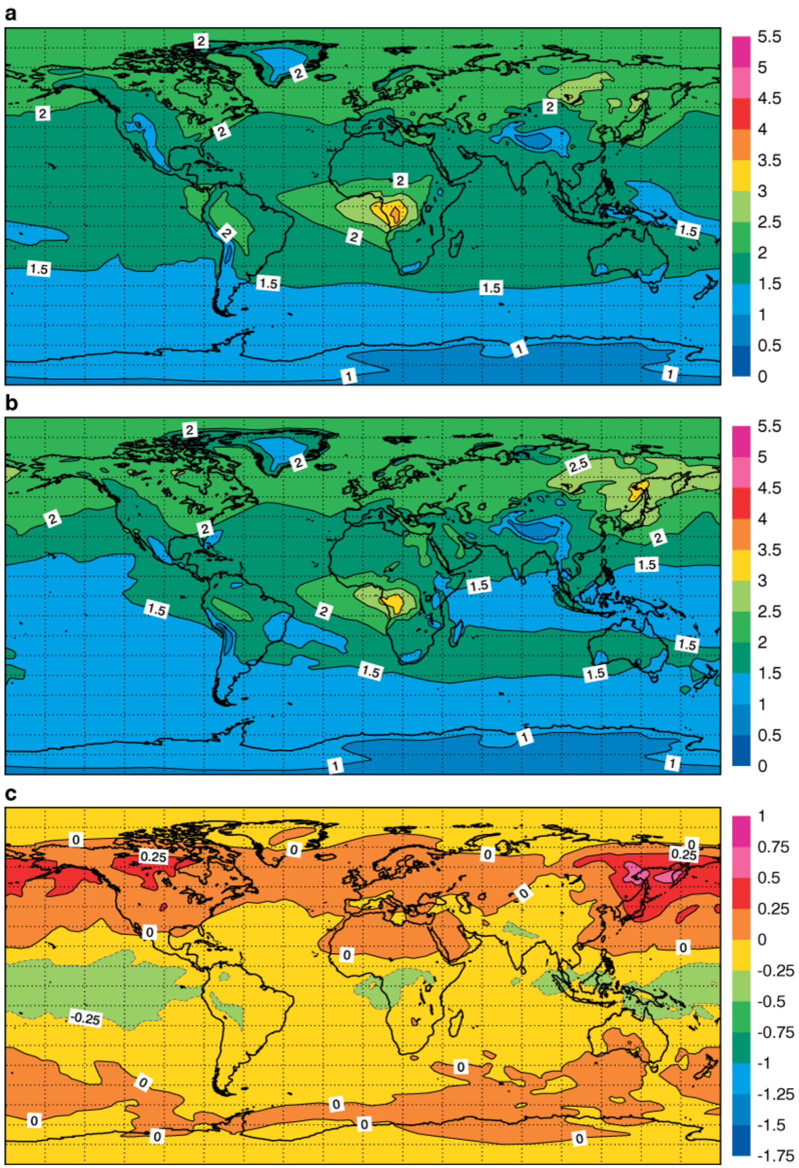
- MOPIT CO total column assimilated for July 2003
- Chemistry assimilation is part of NWP meteorological 4DVAR
- GRG analysis uni-variat in a statistical sense (Background error matrix)
- Diagnostic NOx inter-conversion operator links NO2, NOx and O3
- Tangent linear and adjoint of coupled system not feasible
- Implementation
  - ➔ Full coupled system in high resolution outer loop
  - ➔ Advection only in inner loop

ECMWF 4D-VAR Data assimilation T,u,v,q,O_3



ECMWF

CO Data assimilation



Mean total column CO field
20030715-20030730

(a) the control run

(b) the assimilation run

(c) the difference

Antje Dethof

CO data assimilation - Increment statistics

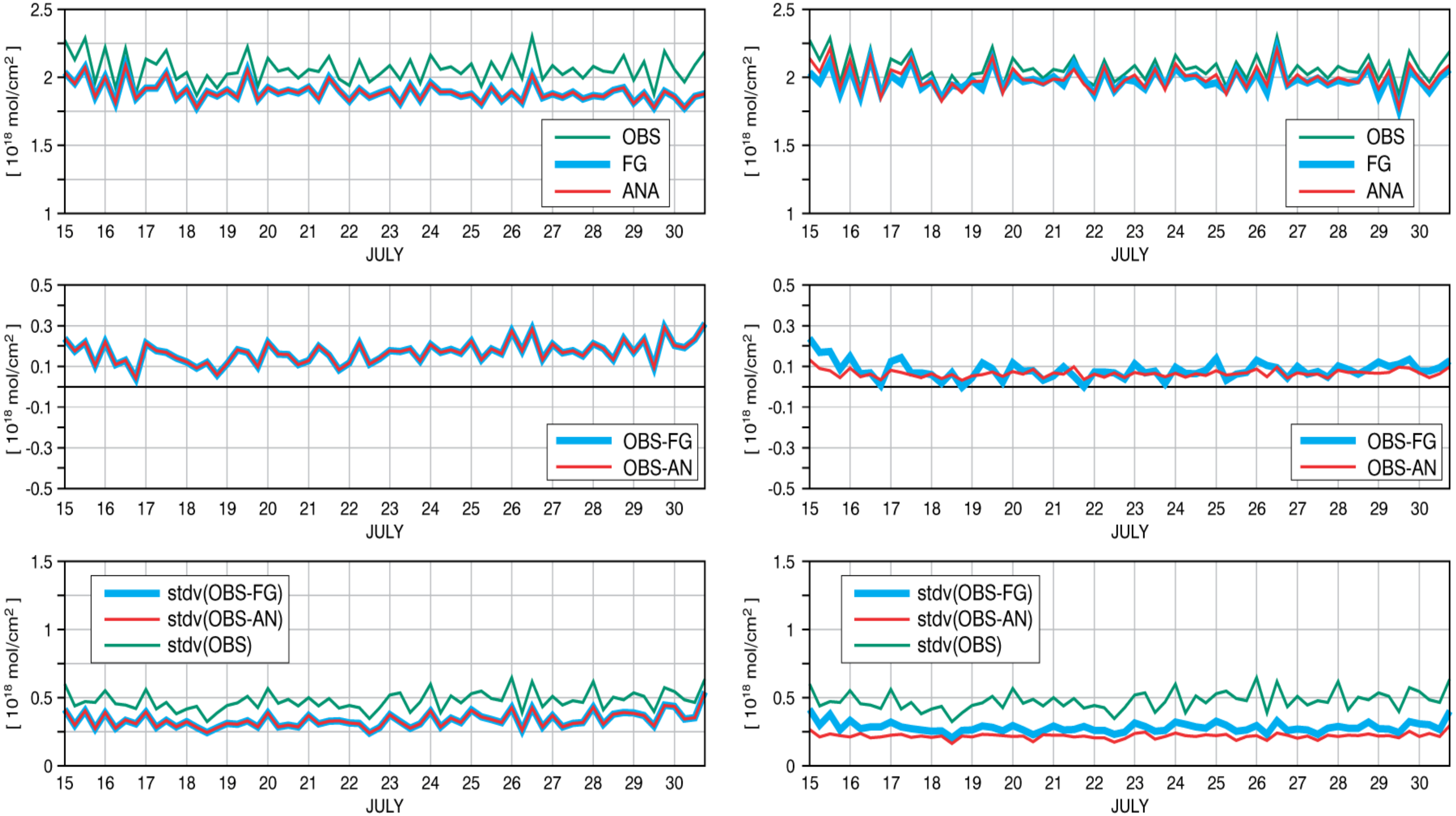
Control

Analysis

Mean

Bias

stdv



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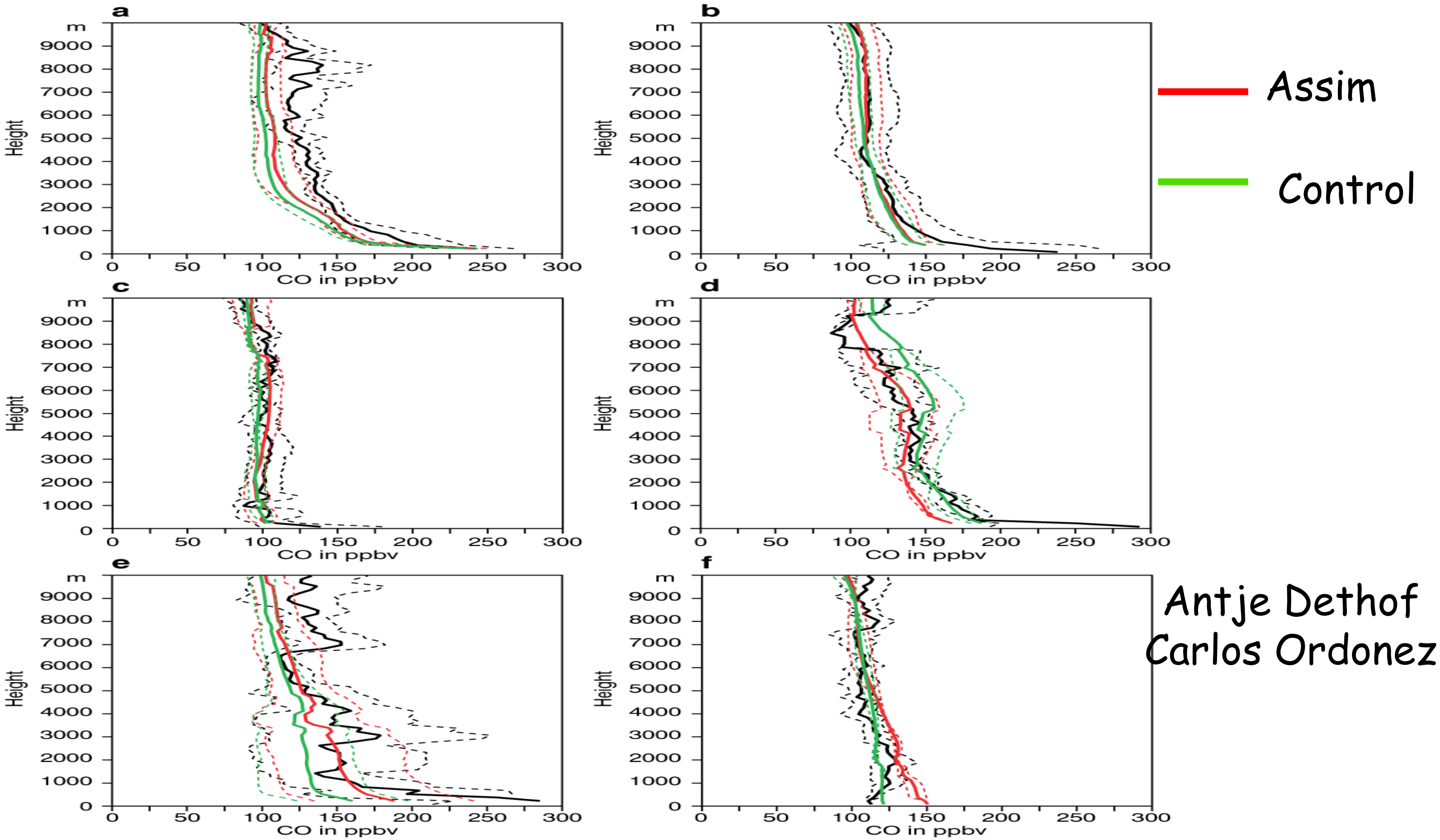
ECMWF

CO Data assimilation -comparison with MOZAIC observation

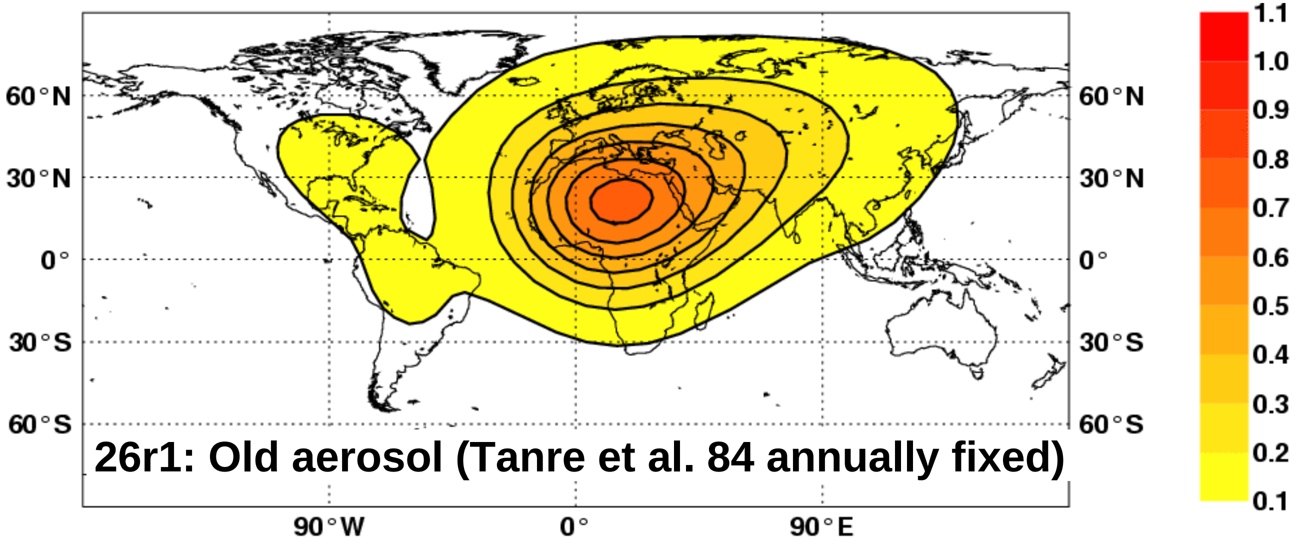


Antje Dethof
Carlos Ordonez

Interaction of Aerosol and NO2 in IFS NWP

- **Work by Jean-Jacques Morcrette and Adrian Tompkins**
- **Aerosol and absorbing gases desired for:**
  - ➔ **Radiation (direct)**
  - ➔ **Precipitation (in-direct)**
  - ➔ **Satellite data assimilation**
- **Operational model uses climatologies**
- **Using prognostic species fields currently being tested**

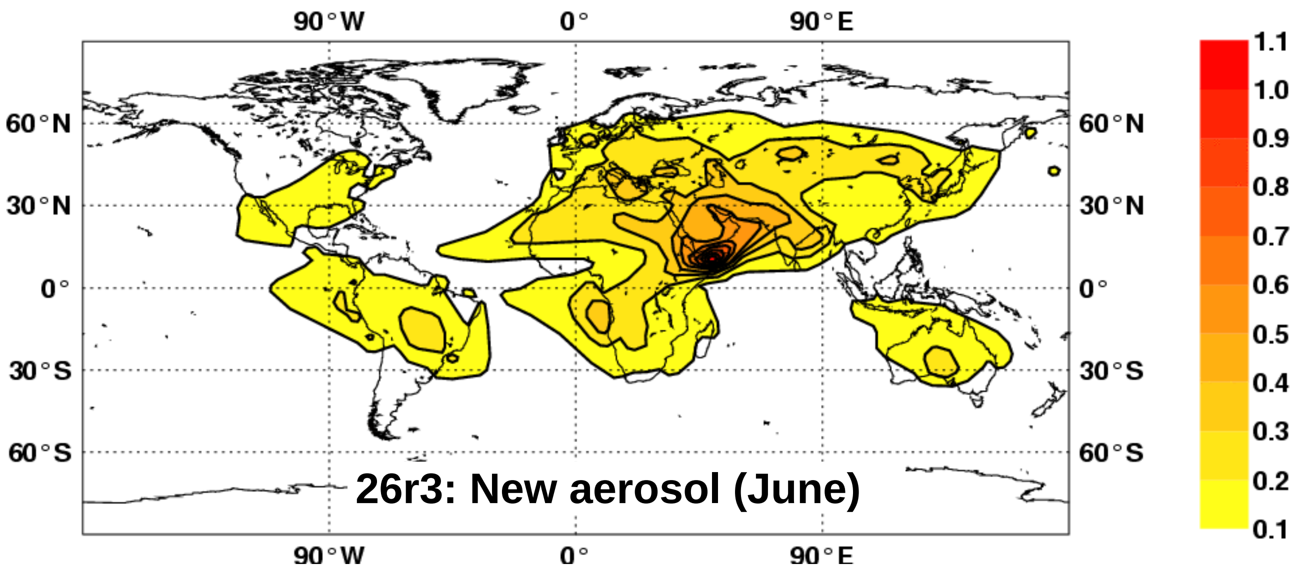
Change in Aerosol Optical Thickness Climatologies



Thickness at 550nm

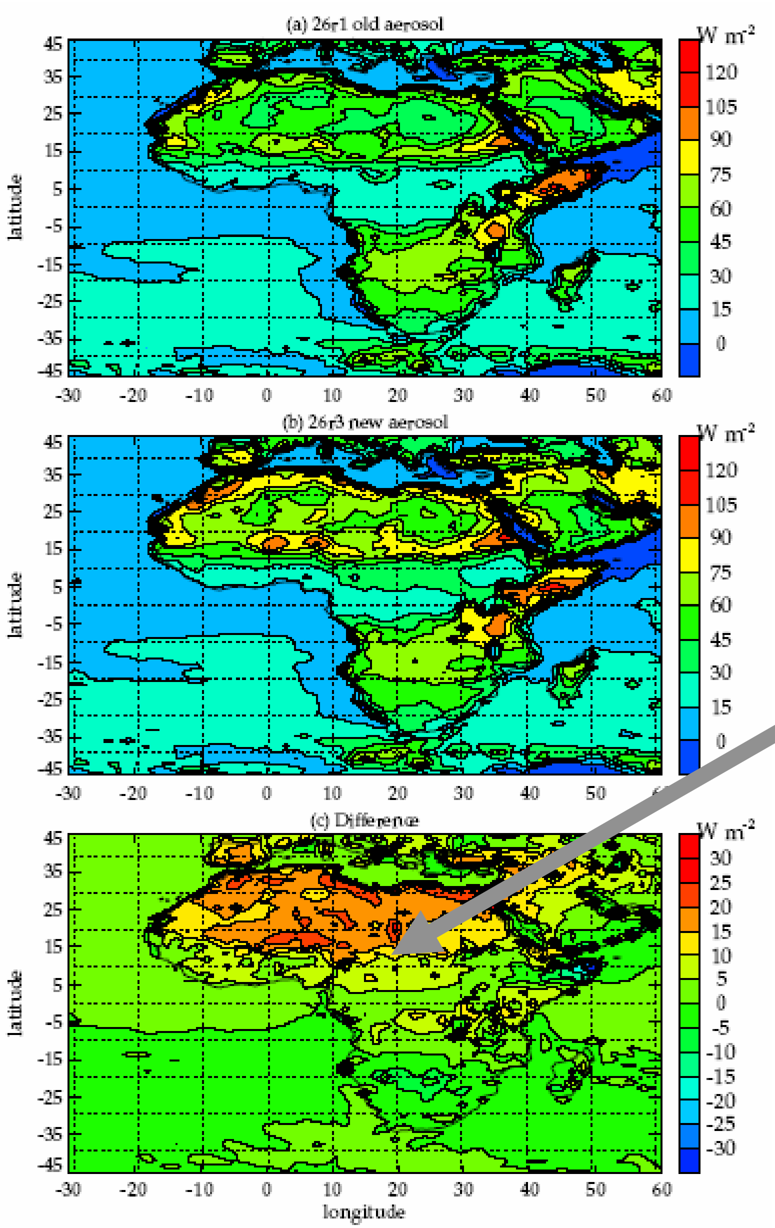
Old aerosol dominated by Saharan sand dust

& increased sand dust over Horn of Africa



New: C26R3 (Tegen et al. 1997): Black Carbon, Sulphates, Organics, Desert Dust, Sea Salt, Volcanic

Surface Sensible heat flux differences

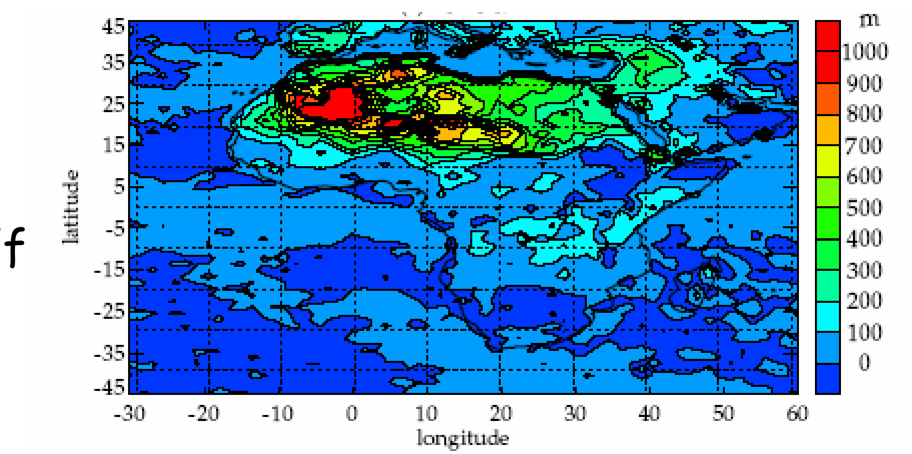


old

new

diff

20 W m^{-2}



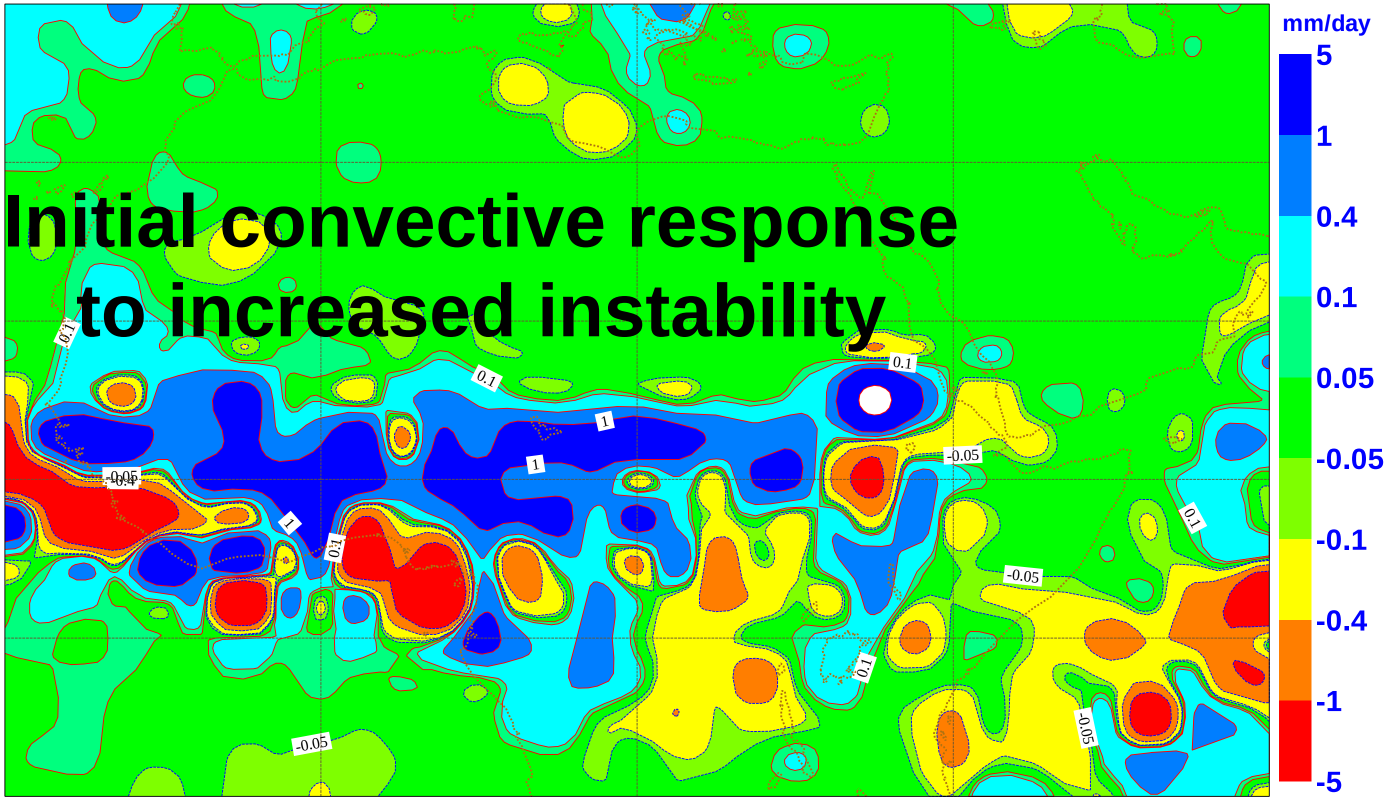
Boundary layer height increases >1km

ECMWF

Effect on diabatic heating location – "direct"

Mean of 4 months of T511 operations, June-September 2003

Total Rainfall Difference, day 0.5-1.5
New Aerosol - Old Aerosol

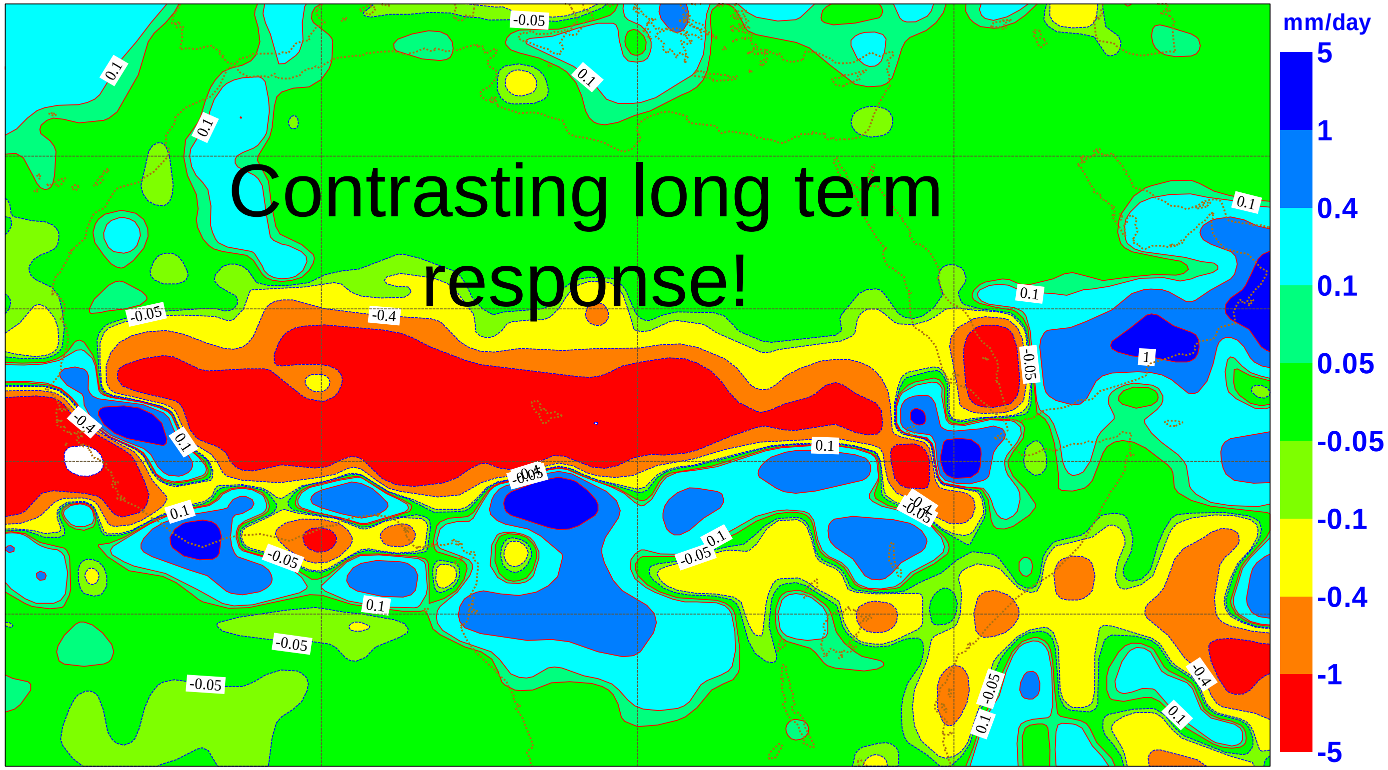


ECMWF

Effect on diabatic heating location

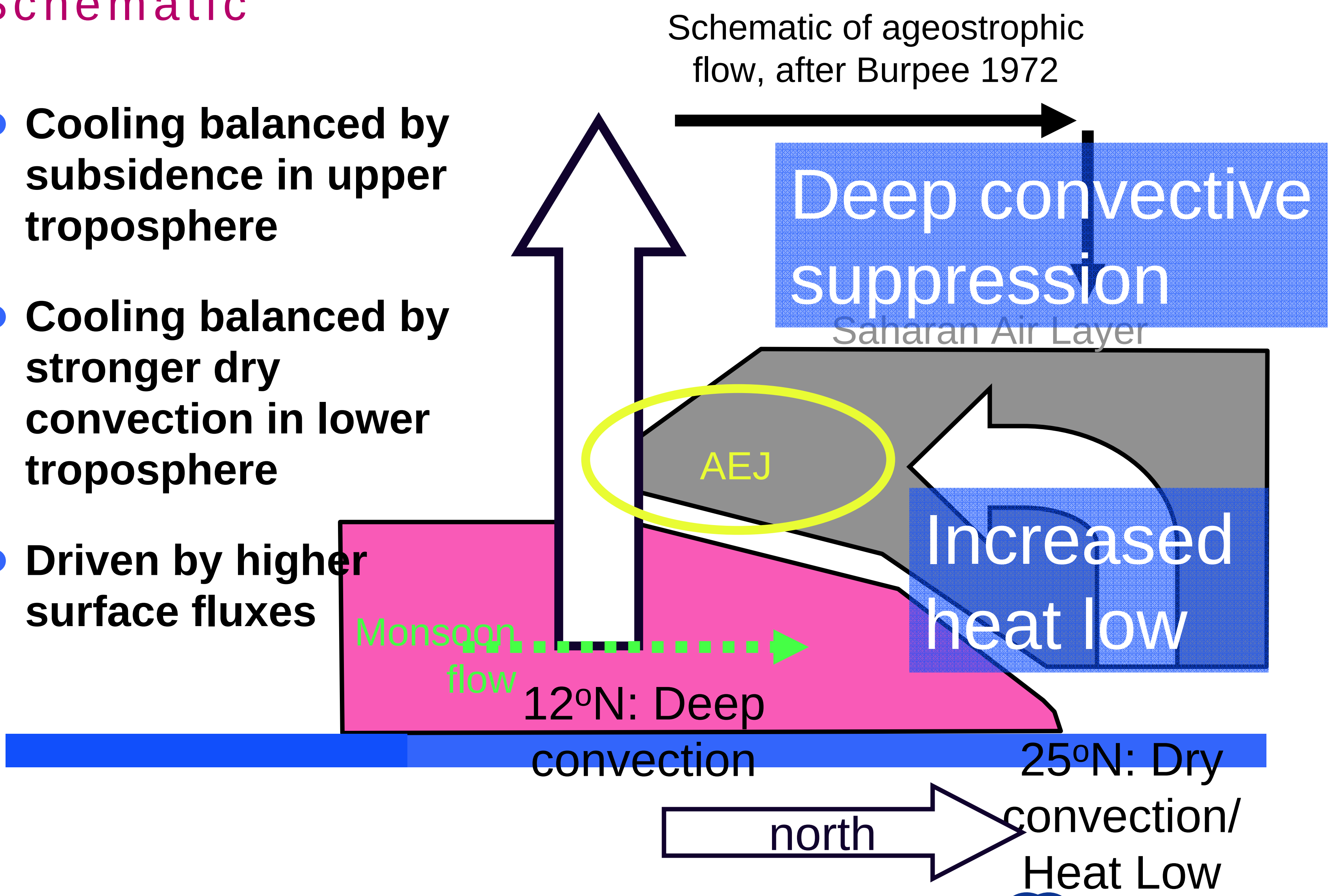
Lack of humidity transport implies cooling balanced by subsidence in medium range

Total Rainfall Difference, day 5-10
New Aerosol - Old Aerosol



Schematic

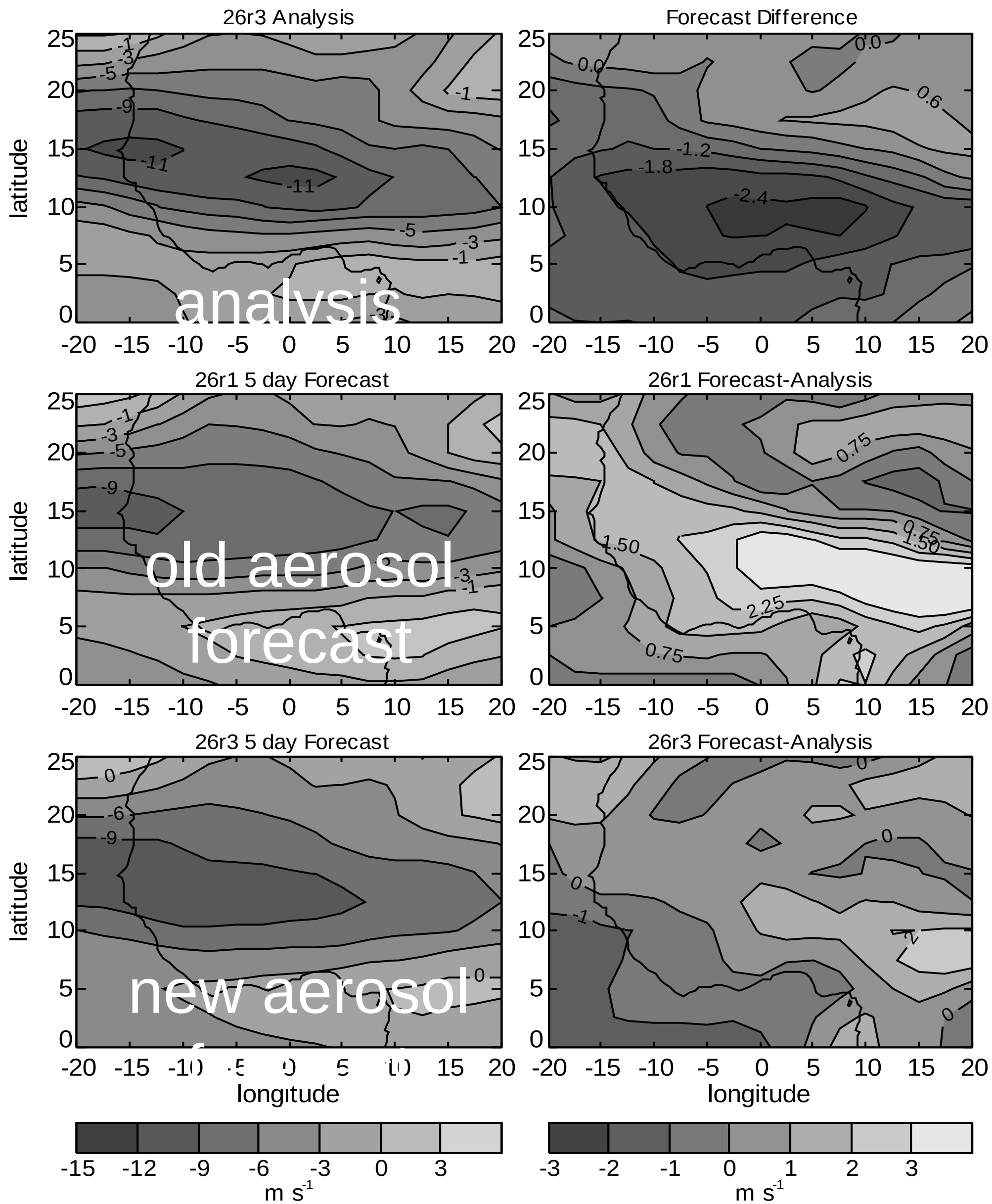
- **Cooling balanced by subsidence in upper troposphere**
- **Cooling balanced by stronger dry convection in lower troposphere**
- **Driven by higher surface fluxes**



Season-mean effect **zonal wind** in 5 day forecast

Mean of 4 months of T511 operations, June-September 2003

Stronger, more extended jet, improved westerlies to south



Warm Rain - autoconversion

- **Aerosol to CCN – Many studies**
- **We use the relationships of Menon et al 1992**

$$N=10^{(2.41+0.5\log(SU)+0.5\log(DD)+0.13\log(OM)+0.05\log(SS))}$$

- **CCN autoconversion – threshold for efficient autoconversion when mean radius exceeds r_{crit}=9.3 microns**

$$q_{crit} = N\,\rho_{liq} 4/3\,\pi\,r_{crit}^{3}\ \rho^{-1}$$

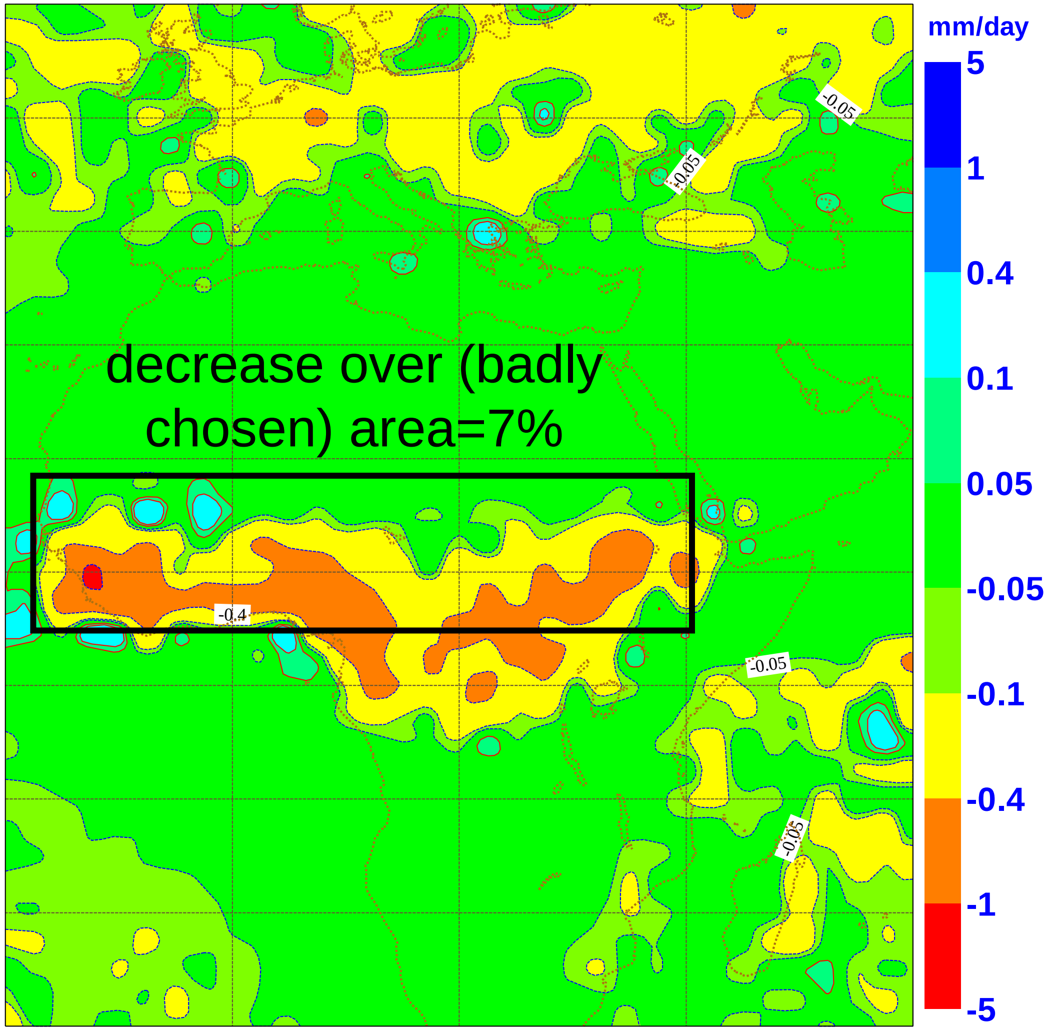
- **Rate coefficient is also proportional to $N^{-1/3}$**

Test bed

- **Two runs conducted**
  - ➔ **1.5 x Tegen Dust**
  - ➔ **0.5 x Tegen Dust**
- **Only indirect microphysical effects allowed**
  - ➔ **No clear sky radiative impact**
  - ➔ **No impact on cloud radiative properties**
  - ➔ **Short forecast ‘restrains’ dynamics**
- **Very preliminary results!!!**

Warm rain feedback (in-direct)

Total Rainfall Difference, day 0.5-1.5 (3 months)
1.5 x dust - 0.5 x dust



Warm rain processes appear to give significant positive feedback

Change to critical q_{crit} for autoconversion most important, giving 5% reduction (agrees with Rotstayn and Penner)

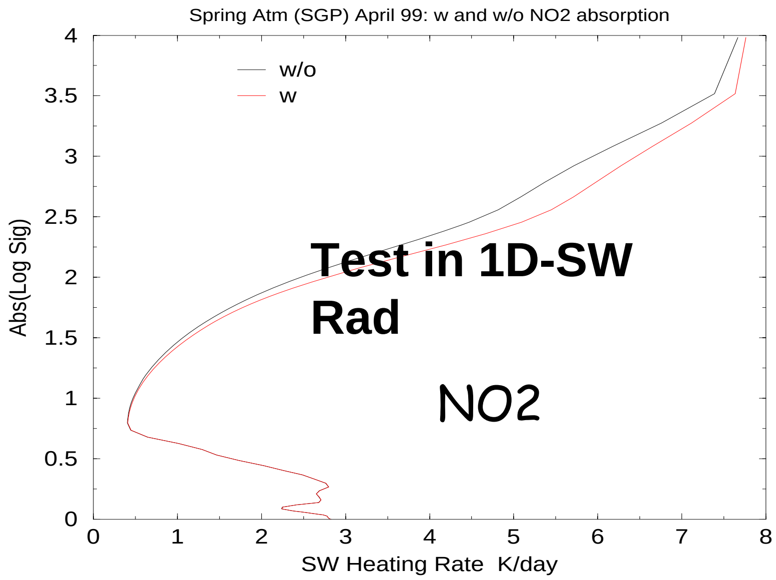
Rate coefficient for autoconversion and collection parameter give additional 2%

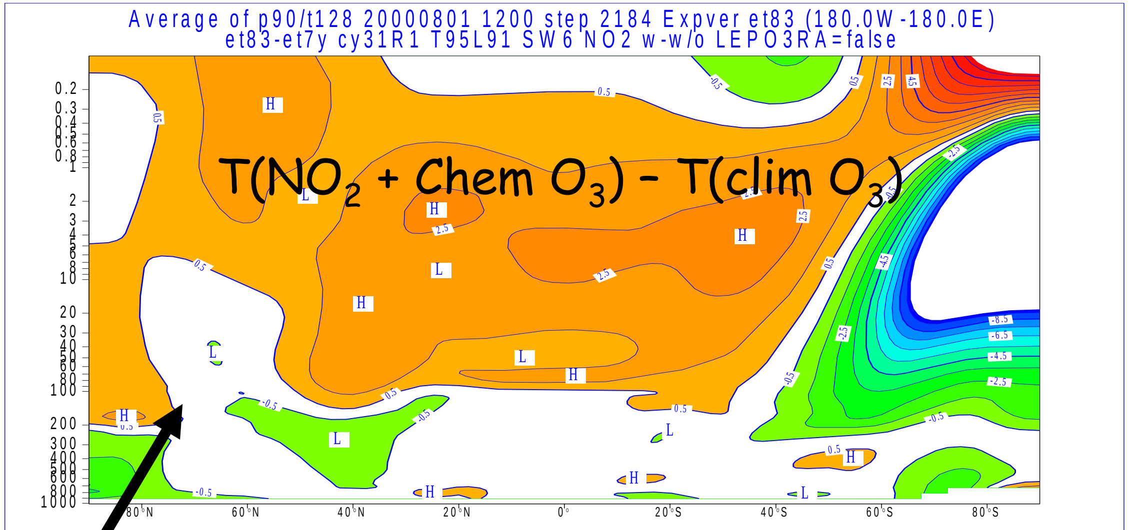
Convection adds further 3%

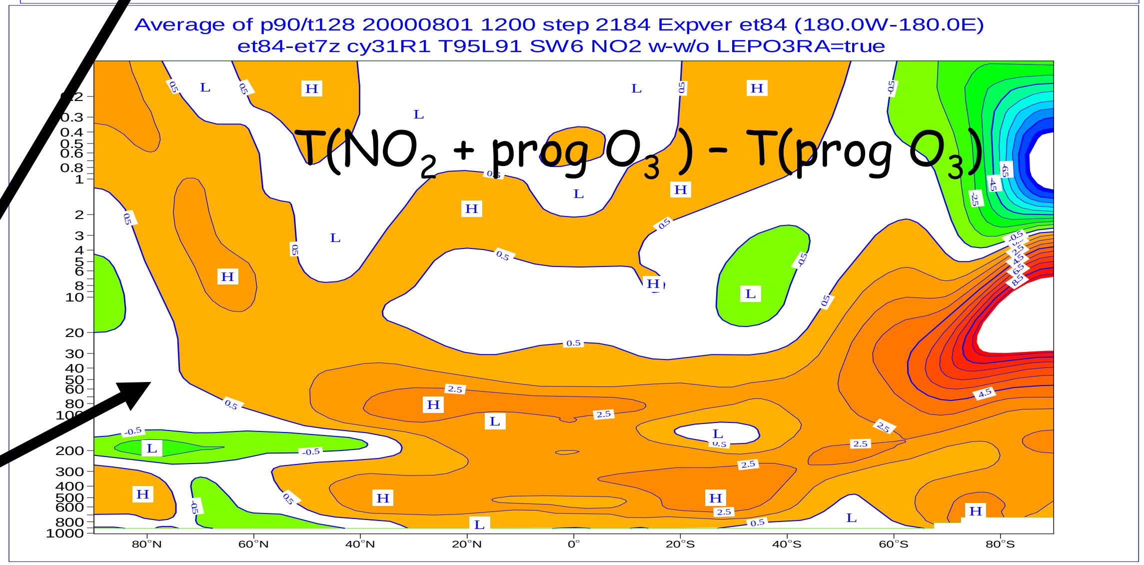
NO_2 and O_3 in present ECMWF SW-6 scheme

- Operational sw radiation scheme use for absorption:
  - ➔ O_3 use the Fortuin and Langematz climatology
  - ➔ NO2, CH4 etc no profile
- Sensitivity experiments:
  - ➔ Using NO_2 climatology from MOBIDIC with the cold temperature bias smaller is improved
  - ➔ using the prognostic O_3 (Cariole scheme chemistry) the cold temperature bias in the lower stratosphere is increased by up to 2K

Radiation O3: climatology vs prognostic







Impact in TL95 L91 3-month runs

w/o O3-Rad interactions

w O3-Rad interactions

Conclusion I

- GEMS Coupled system for forecast and data assimilation in place coupling TM5, MOZART and MOCAGE to the IFS
- System IFS-MOZART computationally most efficient
- IFS can imitate CTM by tendency application – forecast mode works with coupled system
- Data assimilation works with coupled system
- CT-Modeling can benefit from IFS meteorological input:
  - ➔Temporal resolution
  - ➔IFS vertical transport

Conclusion II

- ECMWF NWP Aerosol and reactive Gases feedback:
  - ➔ Direct and indirect effect included based on climatologies – very sensitive
  - ➔ Using prognostic species is work in progress
- Experimental NRT forecasts running
- Next steps:
  - ➔ Conservation issues (Coupler, IFS advection)
  - ➔ Including more chemistry in minimization
  - ➔ Integrating full chemistry in IFS (?)
  - ➔ More validation by GEMS partners

Thank you!

Modes of the coupled system

- Coupled system model runs are sequence of forecasts starting form the operational analysis
- Initial conditions for the IFS and the CTM from:
  - ➔ CTM – "CTM constrained"
  - ➔ Previous run – "free running"
  - ➔ Tracer feedback IFS to CTM
- 3D Chemistry + 3D (Emission & Diffusion) + 3D Deposition tendencies in IFS (IFS does advection only)
- 3D Chemistry + 2D Fluxes (IFS does advection, convection and diffusion & emission)