Ozone-radiation interaction in assimilation with the GEM model with stratospheric chemistry

A task of the ESA contract in coupled chemical-dynamical data assimilation

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Content

- Introduction to the model and data assimilation system
- Results of free model runs (Aug-Oct 2003)
- Preliminary assimilation results (Aug. 2003; analyses, and short and medium-range forecasts)
- Conclusion
- Very near future plans

Introduction: The GEM-BIRA coupled model

- Based on the extended version (GEM-Strato) of the Canadian operational weather prediction model (GEMDM)
- Resolution: 120x240 (1.5º x 1.5º), L80 with a 0.1hPa ceiling.
- Δt = 45 min with radiation code (to update heating/cooling rates) called every time step.
- The computation of the radiative processes is based on the correlated k-distribution method (Li & Barker).
- Includes orographic and non-orographic Gravity Wave Drag (GWD) parameterization schemes
- Use of on-line and optionally interactive (O_3 and H_2O) photochemical module developed at the Belgium Institute for Space and Aeronomy (BIRA).
- Fortuin and Kelder ozone climatology can instead be passed to the radiation code (average based on HALOE used above 0.5 hPa).

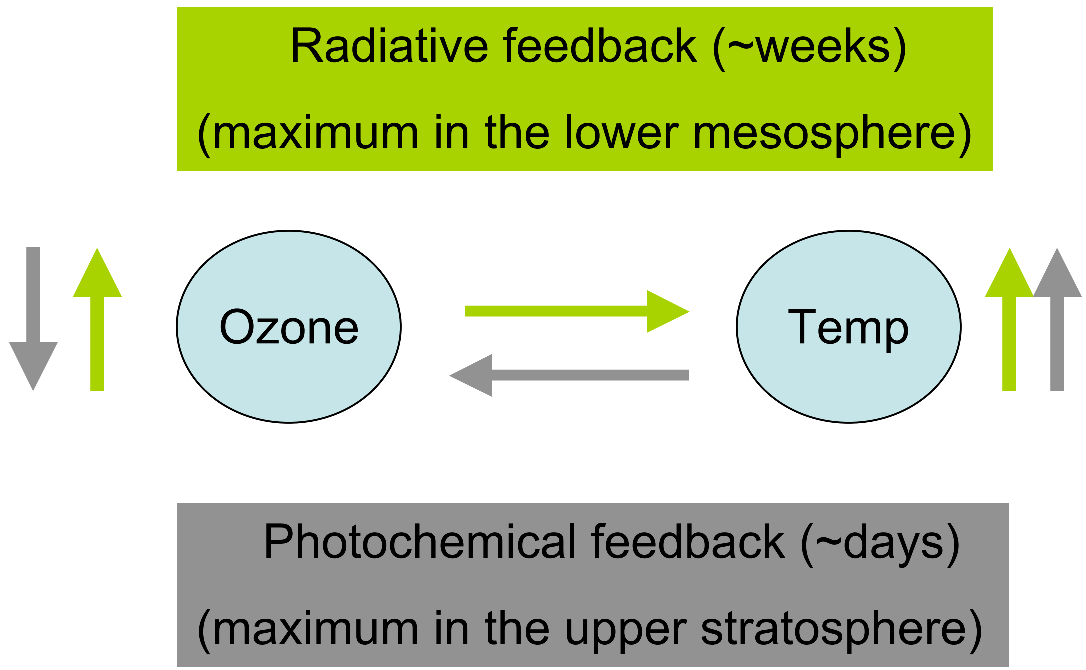
Introduction: The BIRA photochemistry

- 57 constituents from the Ox, HOx, NOx, ClOx, BrOx families including few hydrocarbons
- Source species: N_2O, CH_4, H_2O, CFCs and Halons
- 194 photochemical reactions
- 7 heterogeneous reactions
- Photochemical rates are taken from JPL-2002
- Chemical solver: 3^{rd} – order Rosenbrock
- Photodissociation rates : Look-up table approach.
- Semi-Lagrangian transport of all constituents
- H_2O-radiation interaction turned on.

Introduction: The data assimilation method

- 3D variational assimilation scheme
- Uses the EC weather forecasting system 3D-Var adapted to assimilate both/either meteorological and chemical observations.
- Same vertical levels as the model (L80)
- Background errror statistics:
  - Std. dev. are a function of latitude (120) and vertical level (L80).
  - Correlations are in T108 spectral space and imply isotropic, homogeneous and non-separable correlations in physical space.
  - Covariances from meteor. variables currently from the NMC method
  - Covariances for chemical constituents currently reflect gaussian correlation functions with HWHM of 400 km in the horiz. and 2 km in the vertical, and std. dev. at 20% of a typical zonal mean field.

Diagram of photochemical-radiative feedbacks in a coupled model

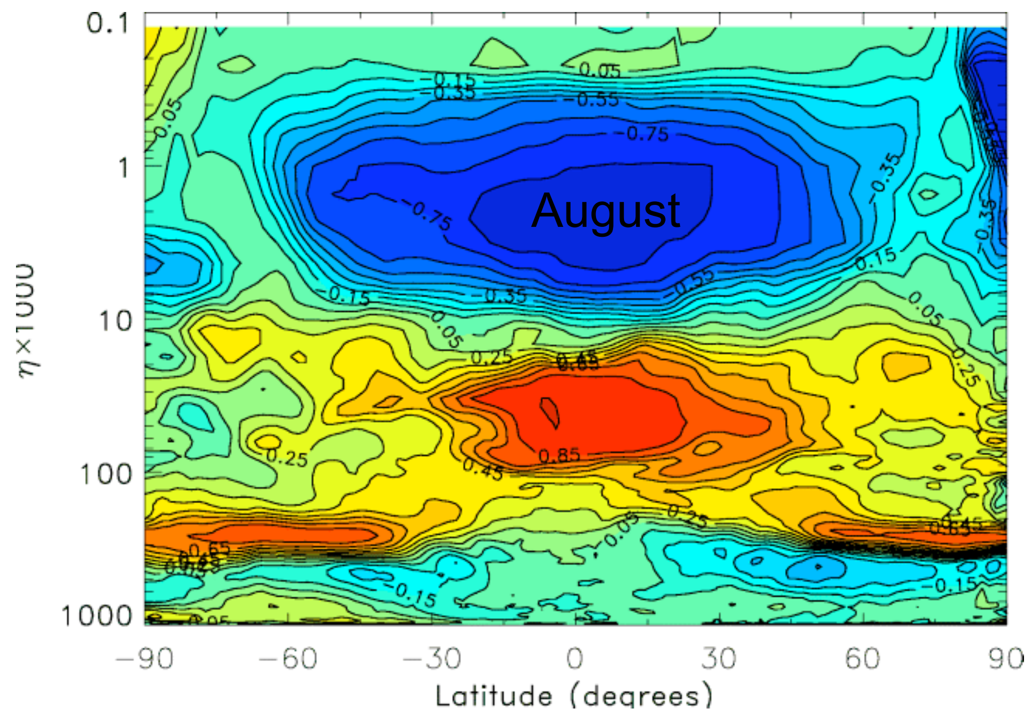


- The photochemical interaction occurs through the temperature dependencies of the reactions which destroy ozone.
- To assess the photochemical module, it is necessary to drive the model with **very good temperature analyses**.

Ozone – Temperature cross-correlations (includes ozone-radiation interaction)

- Since the ozone production rate increases with decreasing temperatures, there is negative correlation in regions dominated by photochemistry (above ~35 km) as compared to radiative feedback. (this is based on 6-hr differences – short time scale behaviours)

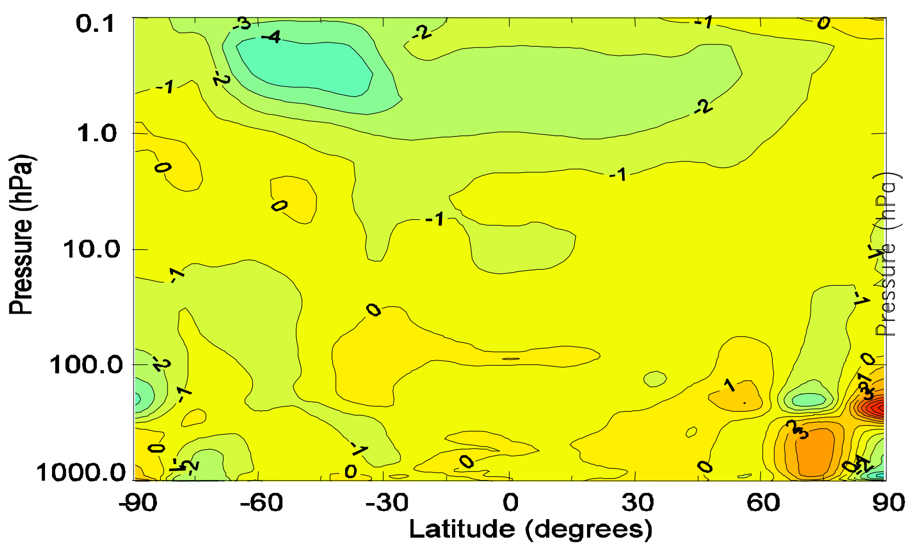
- Correlations related to winds (tracer) also contribute correlations in lower atmosphere.



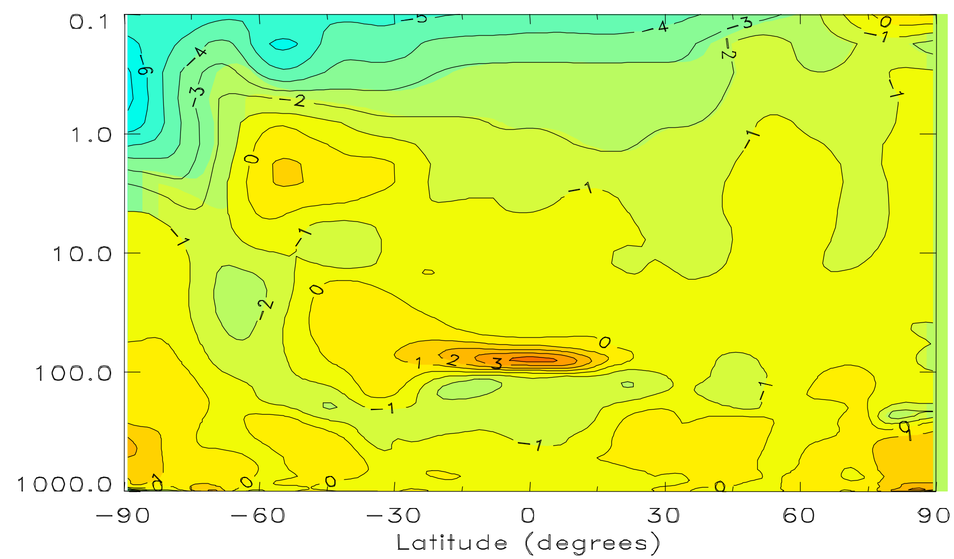
Results of free model runs
(from study by Simon Chabrillat)

- Study on impact of frequency in updating heating/cooling rates shows that updating every timestep instead of every few time steps impacts temperatures. This is a reflection of sun position.
- Updating every time step therefore provides a better representation and reflection of the sensitivity to ozone.

T(rad=1) – T(rad=4), climato O3, 10 last days of 31-day simulation



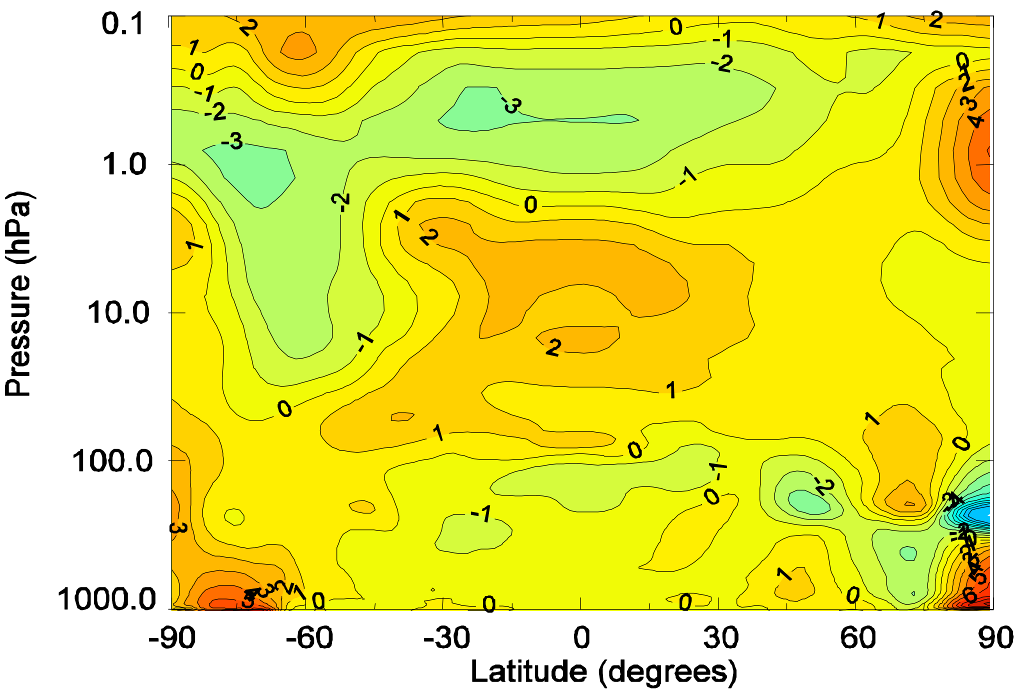
T(rad=1) – T(rad=4), interactive O3, 10 last days of 31-day simulation



Impact of interactive ozone

Results of free model runs
(from study by Simon Chabrillat)

T (interactive O_3) – T (climate O_3)
Aug: 10 last days of 31-day simulation



→ After one month, interactive ozone heats the mid-strato and cools the upper strato by a few degrees.

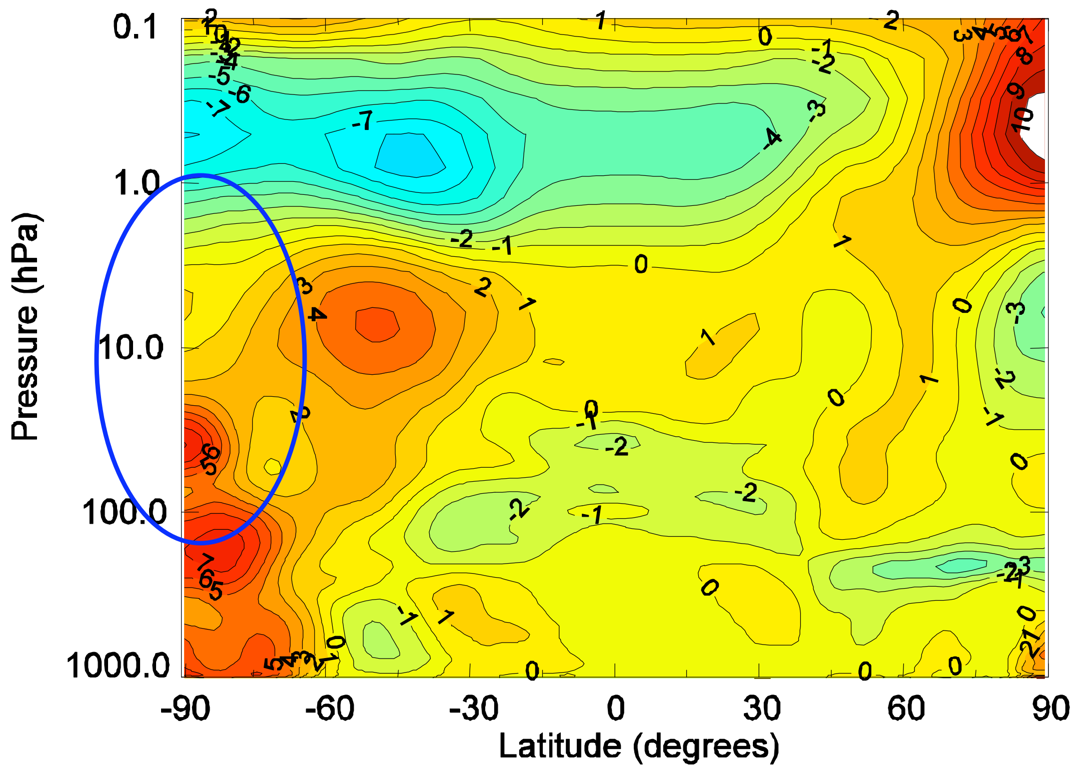
Exceptions:

- upper strato, polar day (large heating)
- tropo poles (variability?)

Impact of interactive ozone

- Larger impact of interactive ozone after 3 months:

T (interactive O_3) – T (climate O_3)
Oct: 10 last days of 90-day simulation



→ After three months, much larger impact especially at mid-latitudes.

South Pole, lower strato: very high variability (vortex break-up)

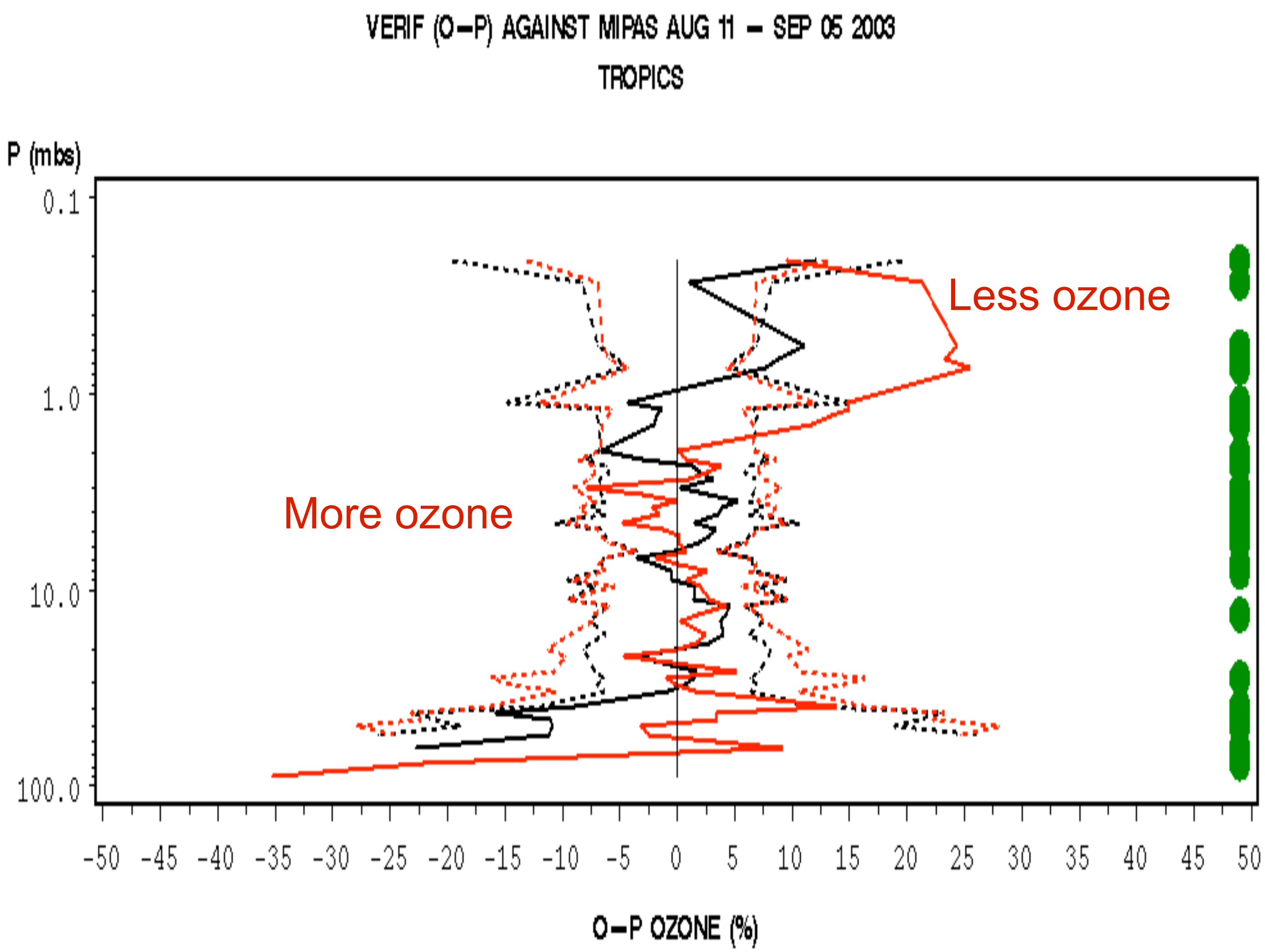
→ Climate experiments (years of simulations) show impact reaching 10K in upper strato with biggest impact above South Pole (polar vortex break-up!!)

Assimilation of AMSU-A temperatures

- Period: 11 Aug. to 6 Oct. 2003
- Assimilation of strato. temperatures only (not strato. ozone): Initial comparisons between interactive and non-interactive ozone-radiation with GEM-BIRA.
- Points to consider:
  - AMSU-A obs. assimilation biases (without debiasing of ch. 11-14)
  - MIPAS OFL retrieved obs. mean differences with HALOE especially above 1 hPa (related to missing quality control?)
  - Ozone diurnal variability in mesosphere could affect comparisons of OmP and OmA considering ±3 hour time intervals.
- Impact of removing AMSU-A ch. 9-14.

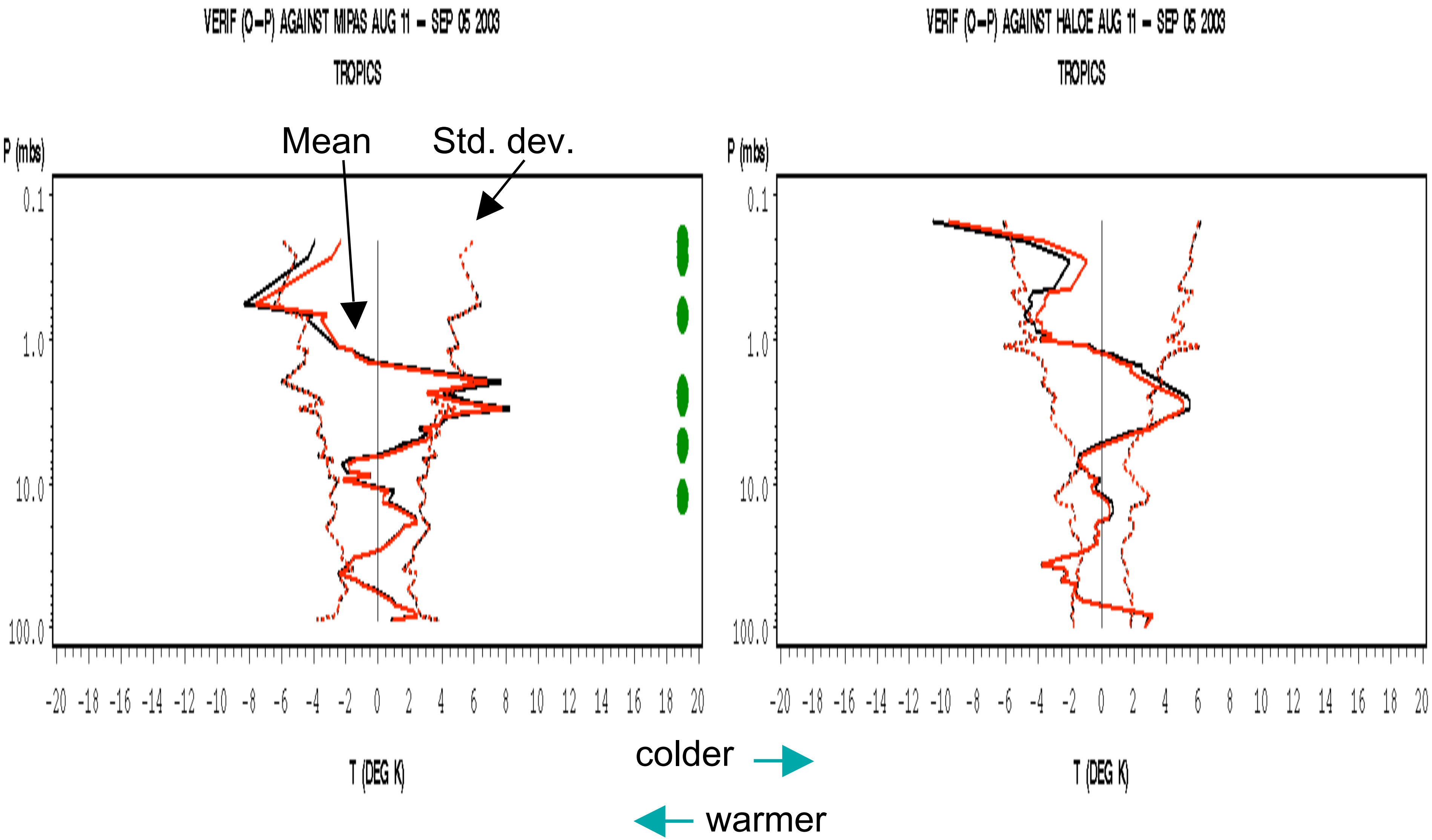
Ozone-radiation interaction in assimilation with GEM-BIRA

Fortuin and Kelder climatology and prognostic ozone in comparison to MIPAS
(prognostic ozone from 6-hr forecasts with ozone-radiation interaction)



Impact of ozone-radiation interaction on 6-hour forecasts

without and with ozone-radiation interaction (no assimilation of ozone)



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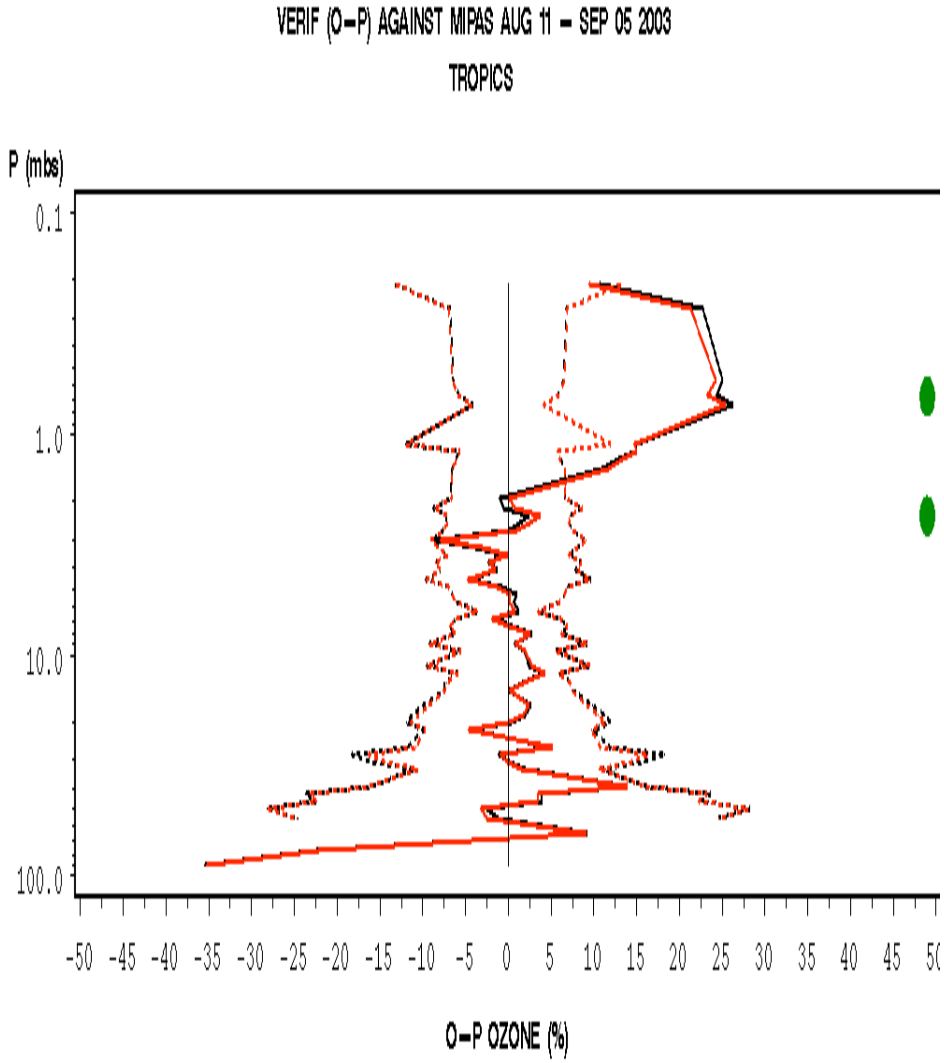
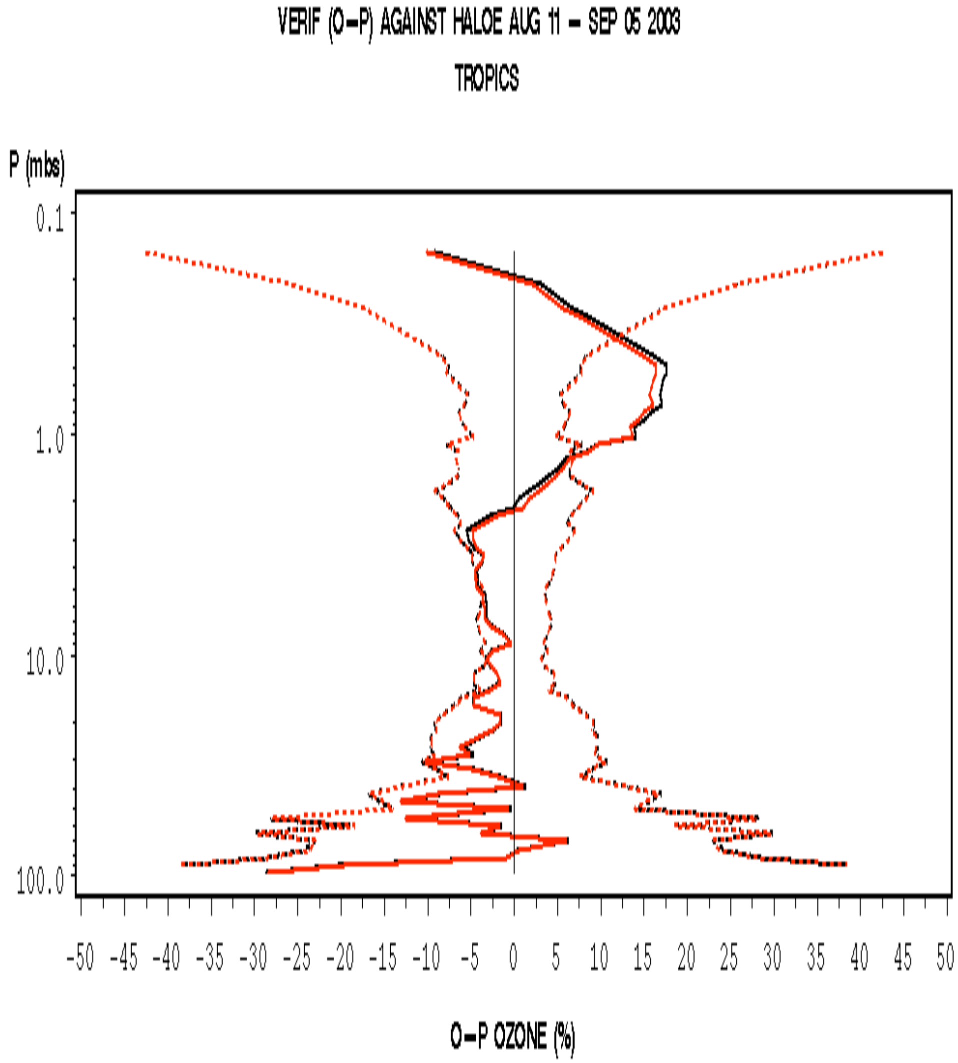
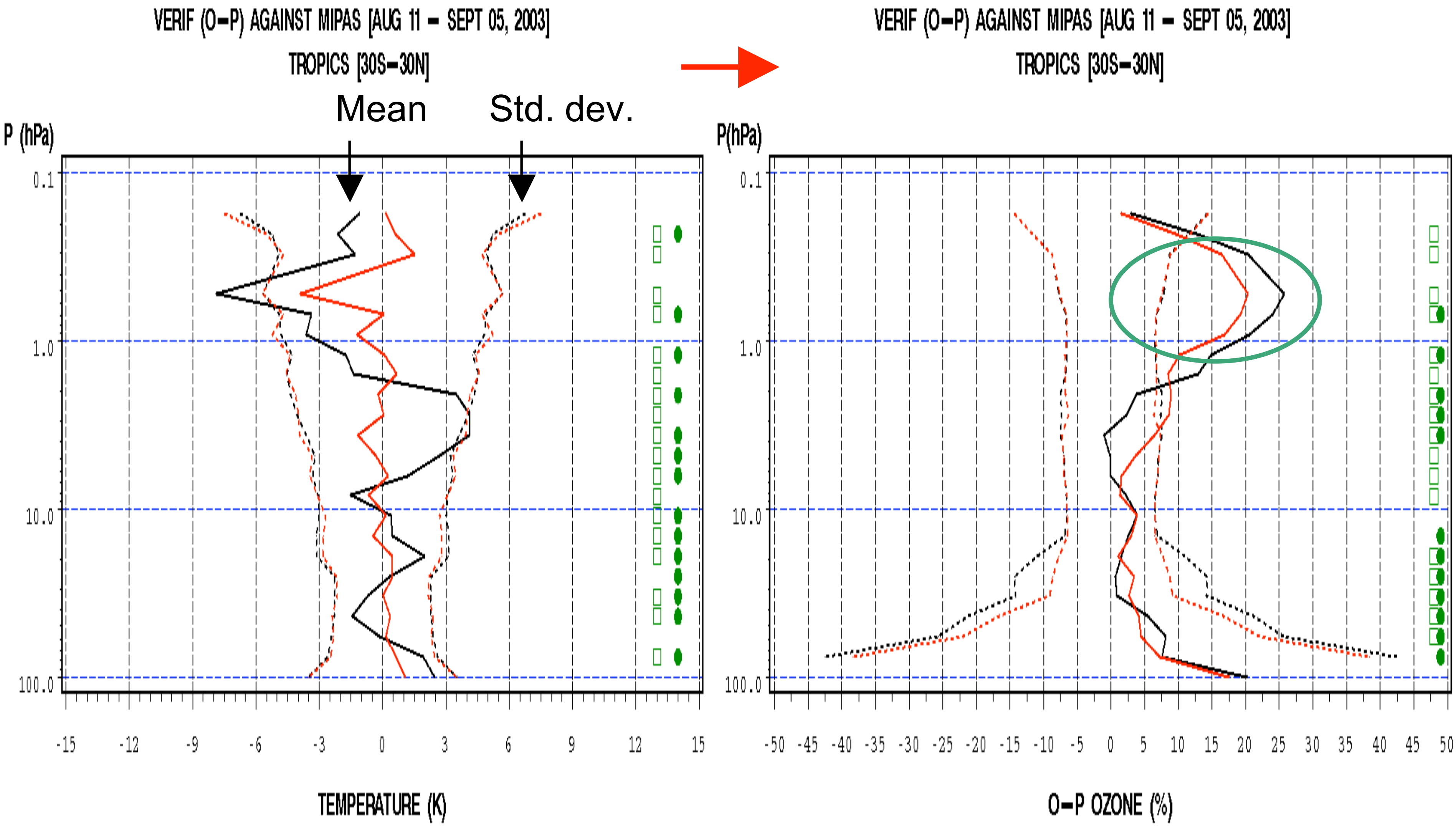




Impact of AMSU-A on 6-hr forecasts (relative to MIPAS)

with and without channels 9-14 (not de-biased; no assimilation of ozone)



Ozone-radiation interaction in assimilation with GEM-BIRA

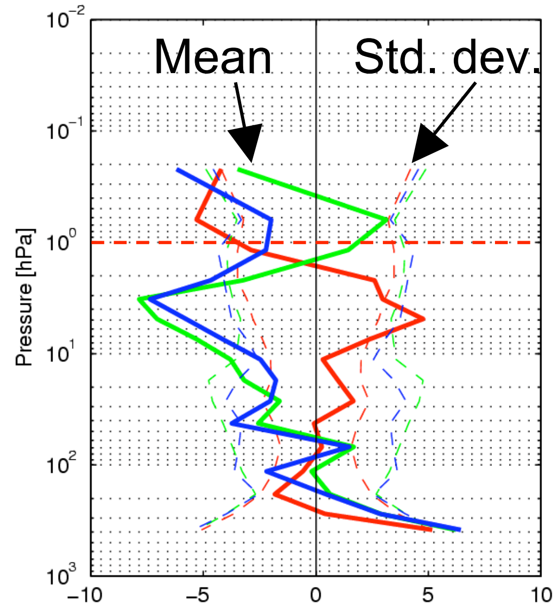
- Sample free model run bias and std. dev. relative to MIPAS

  ECMWF anal.

  Free model with

  interactive O3,

  climate O3



12-21 Oct 2003
within ± 10° lat.

← Obs – model field

(Simon Chabrillat)

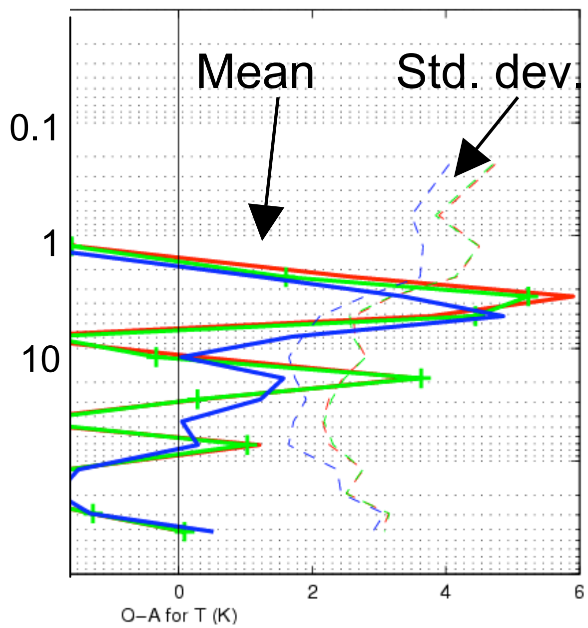
- Sample analysis bias and std. dev. relative to MIPAS.

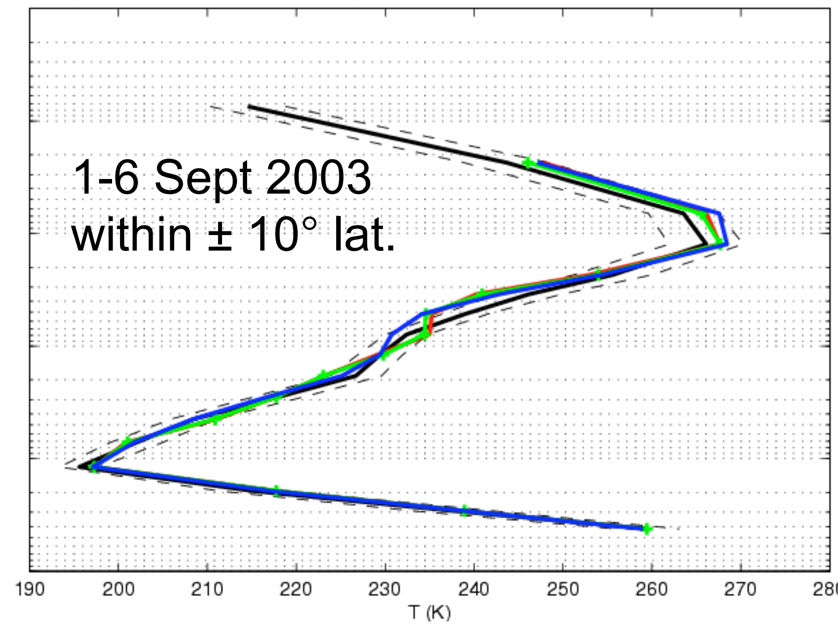
  ECMWF anal.

  Analyses with

  interactive O3,

  climate O3





Assimilation of MIPAS ozone

- Period: 11 Aug. to 6 Oct. 2003
- Points to consider:
  - model biases (in the absence of AMSU-A ch. 9-14)
  - MIPAS OFL retrieved obs. mean differences with HALOE especially above 1 hPa
  - ozone diurnal variability in mesosphere could affect comparisons of OmP and OmA considering ±3 hour time intervals.
- Assimilation of ozone (univariate): First comparisons between interactive and non-interactive ozone-radiation.
- Includes assimilation of RAOBS, aircraft and AMSU-A ch. 3-8 for temperatures.
- Ozone changes was expected to drive temperature changes (radiative feedback) above 300-35 km.

Zonal mean differences with and without MIPAS ozone assimilation for 5 Sept. 2003

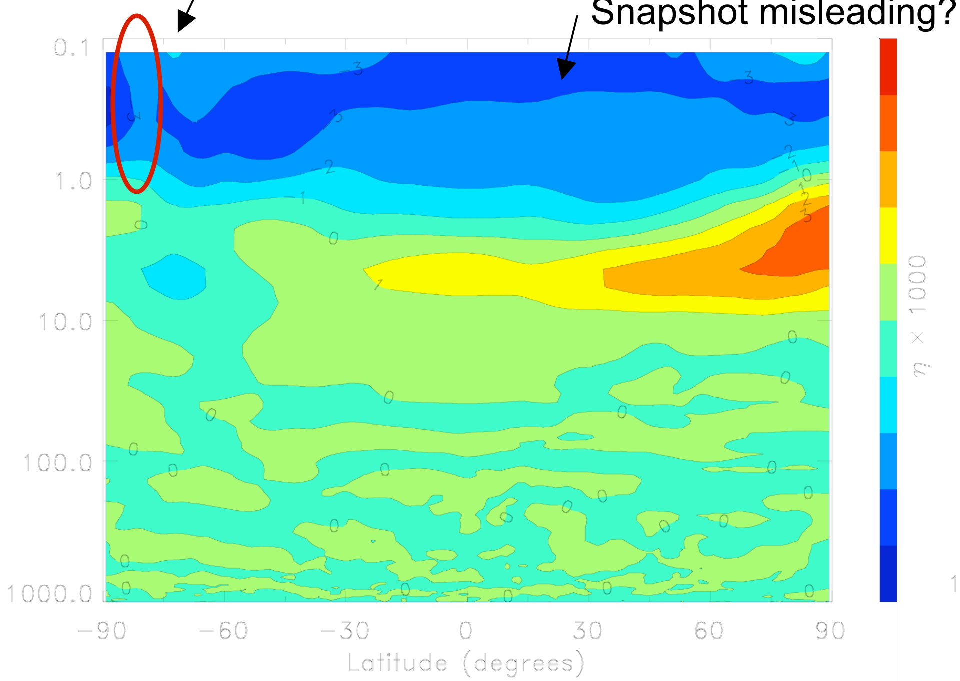
(without AMSU-A channels 9-14)

T(ozone assim.) - T(no ozone assim.)

cooling & ozone decrease

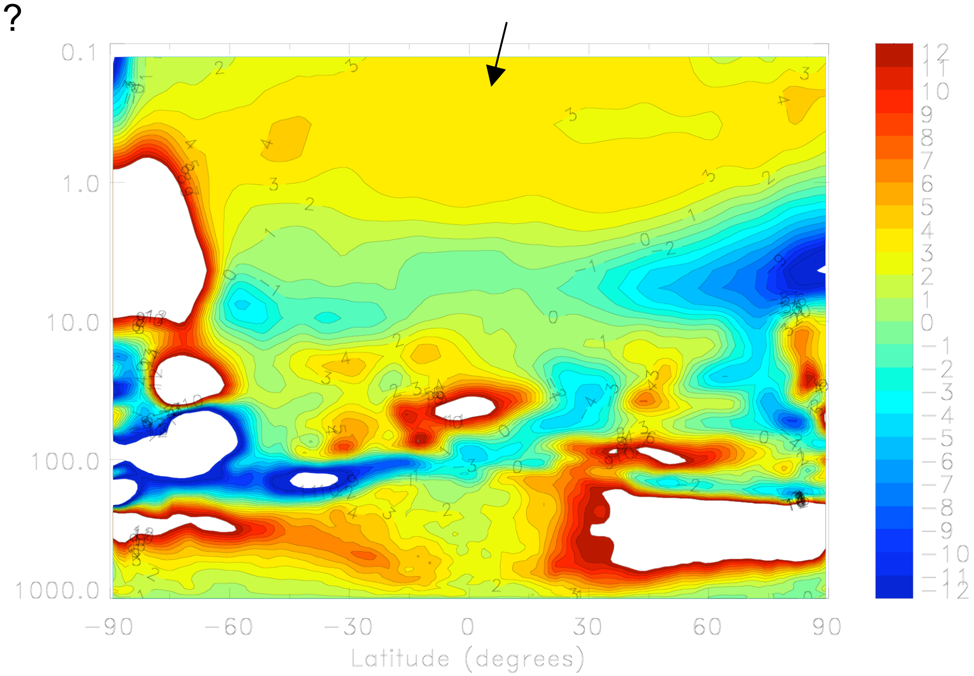
cooling?

Snapshot misleading?



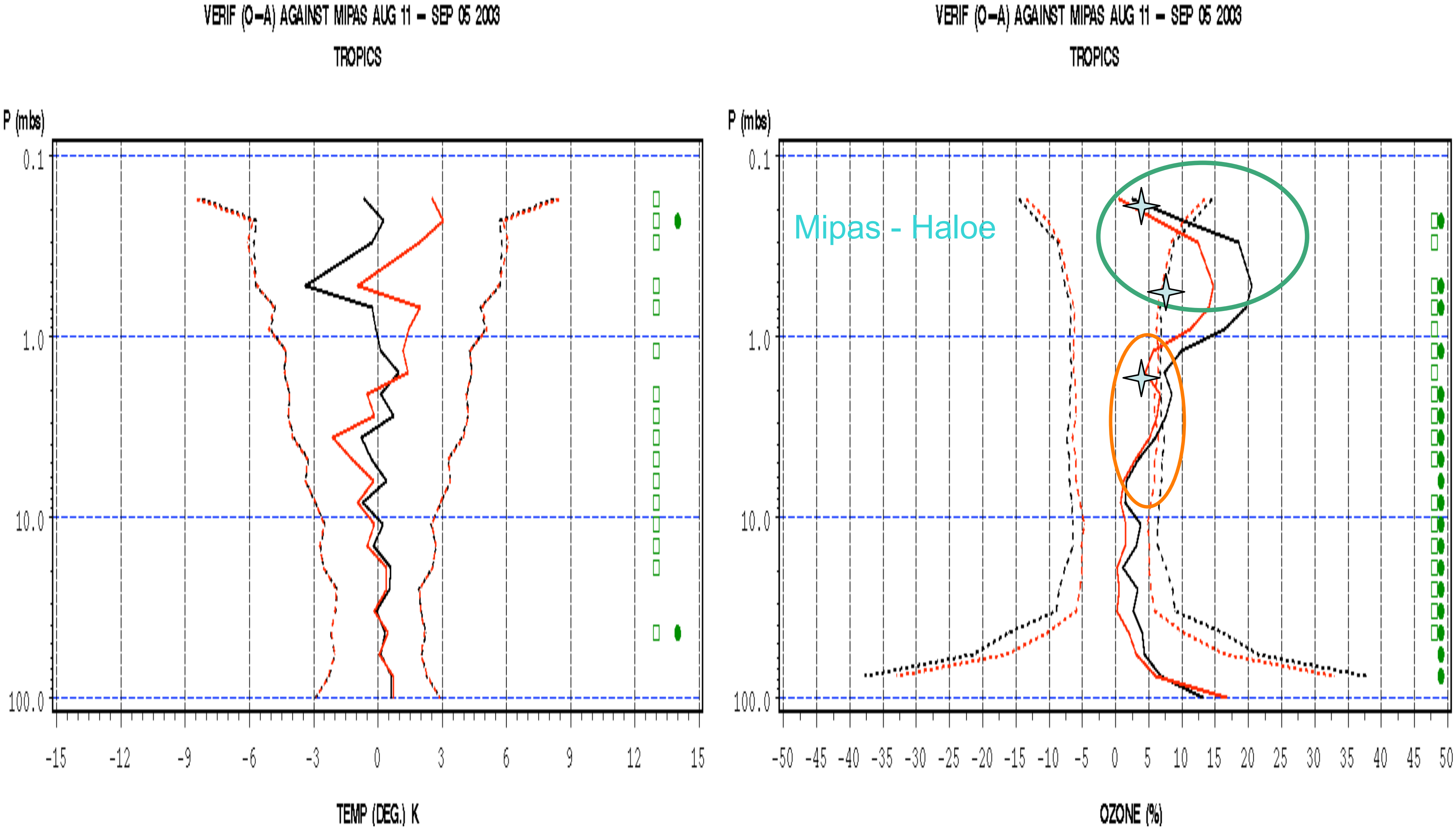
O_3(ozone assim.) - O_3(no ozone assim.)

forced ozone increase



Impact of MIPAS ozone assimilation on analyses

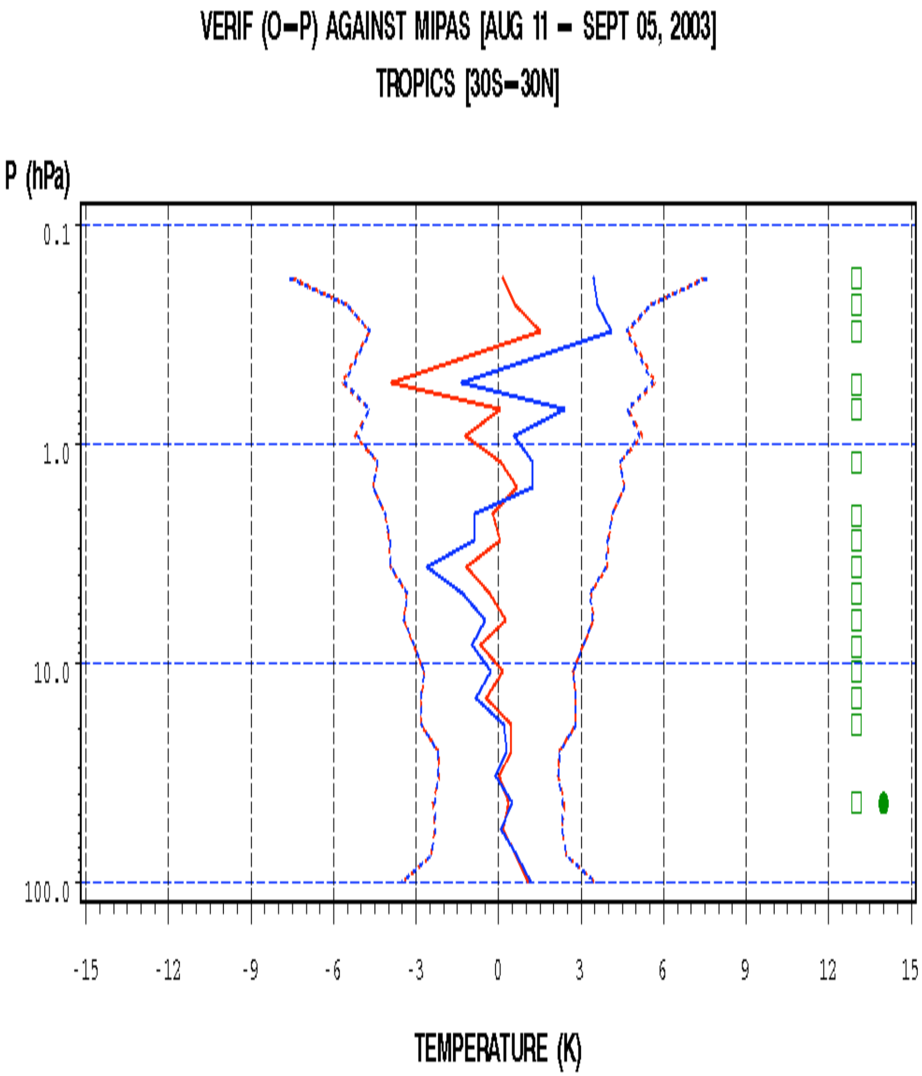
with and without ozone assimilation (without AMSU-A ch. 9-14)

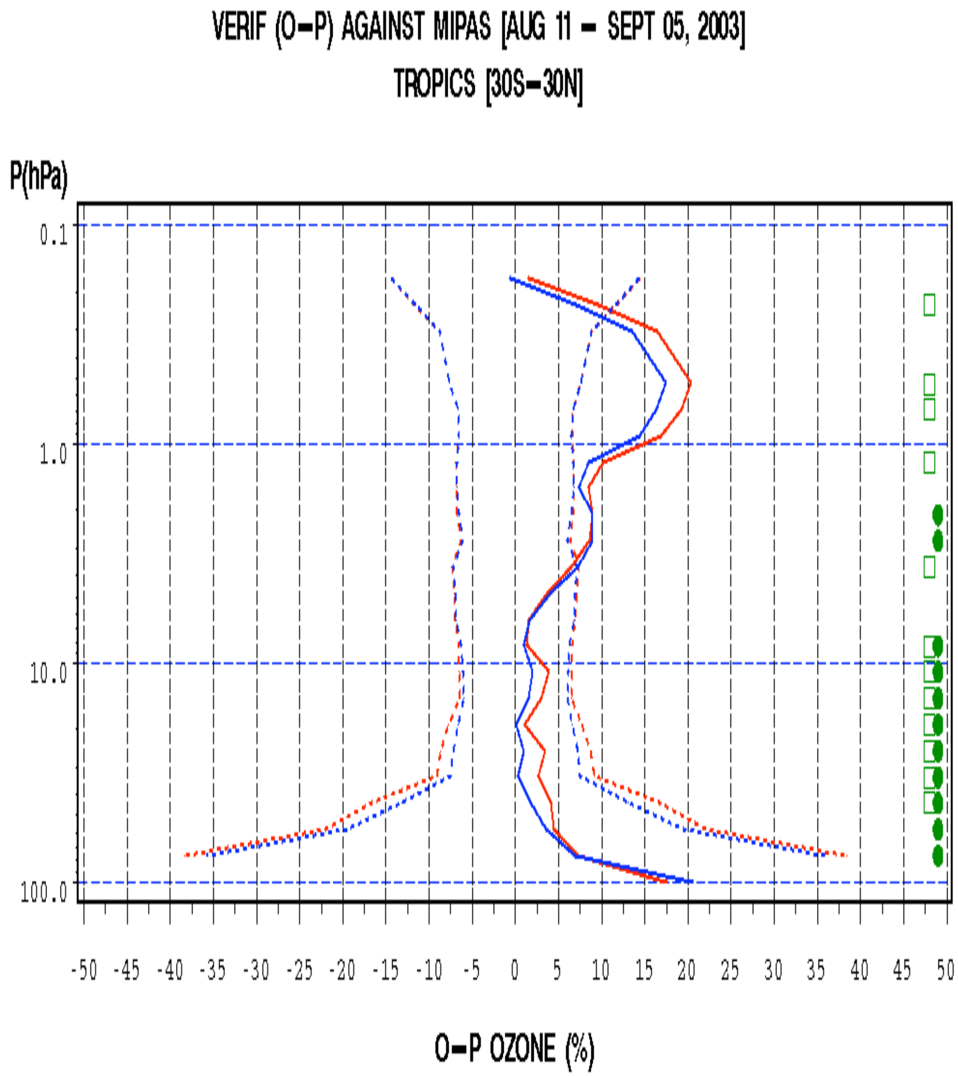


Ozone-radiation interaction in assimilation with GEM-BIRA

Impact of MIPAS ozone assimilation on 6-hr forecasts

with and without ozone assimilation (without AMSU-A ch. 9-14)





Impact of MIPAS ozone assimilation on 6-hr forecasts

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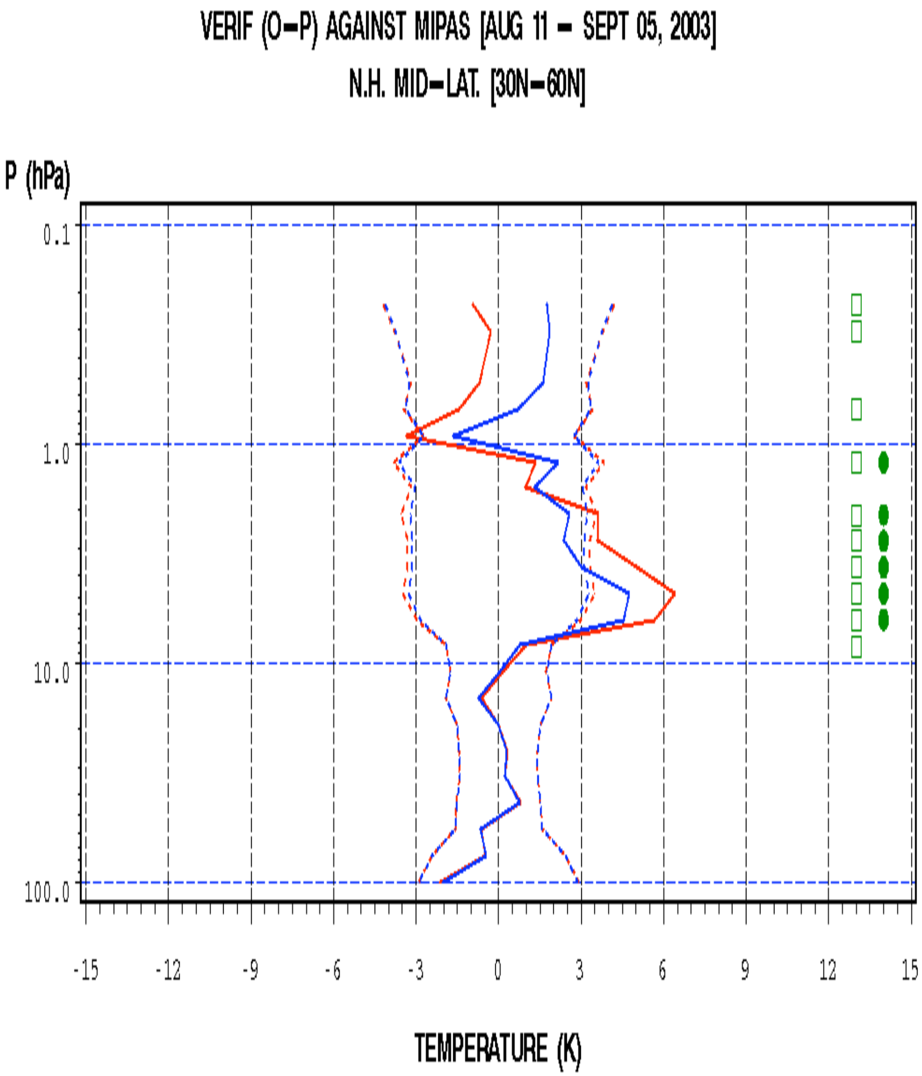

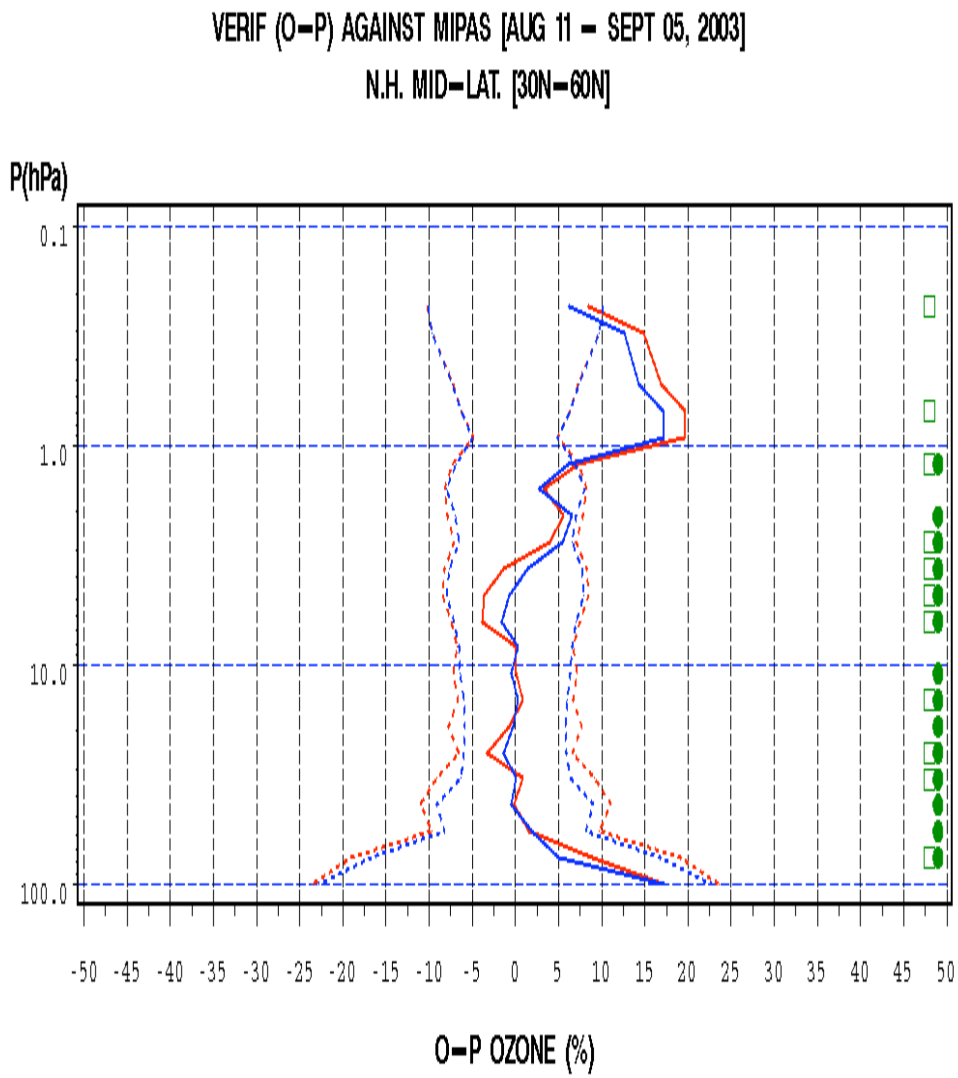

Impact of MIPAS ozone assimilation on 6-hr forecasts

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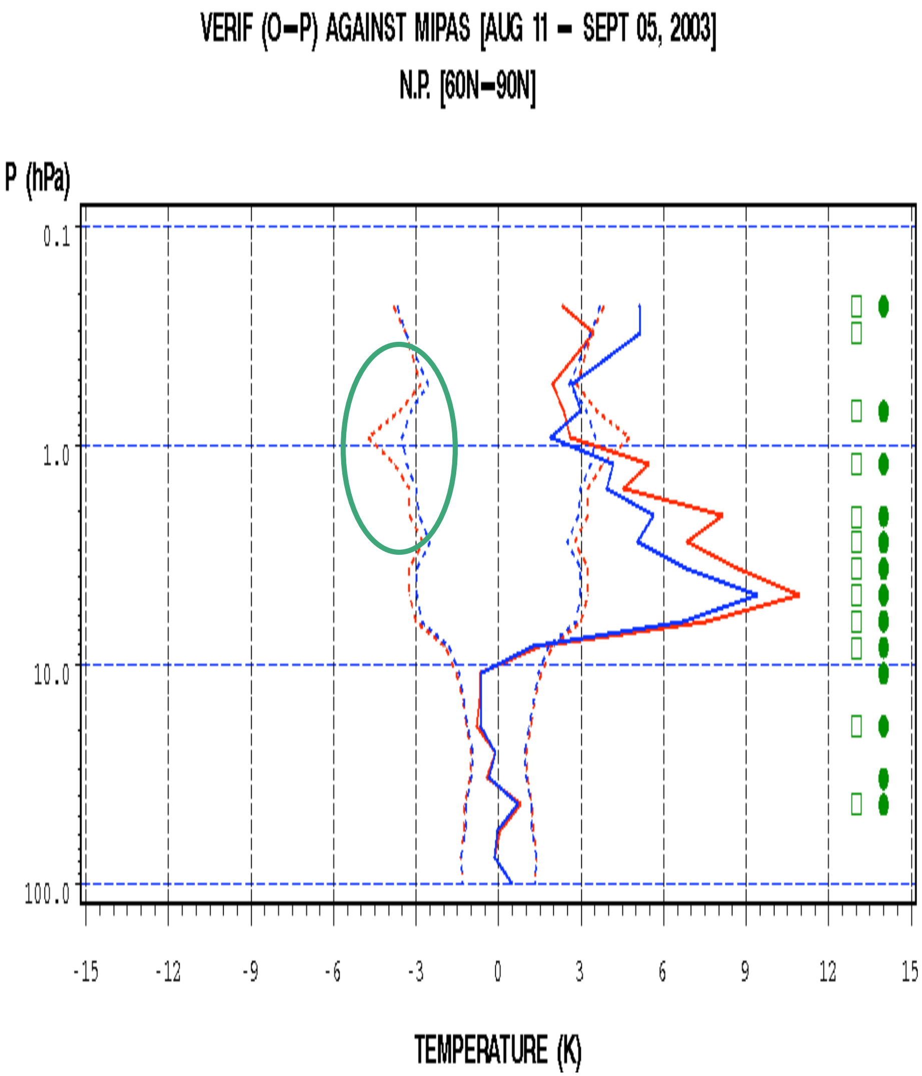

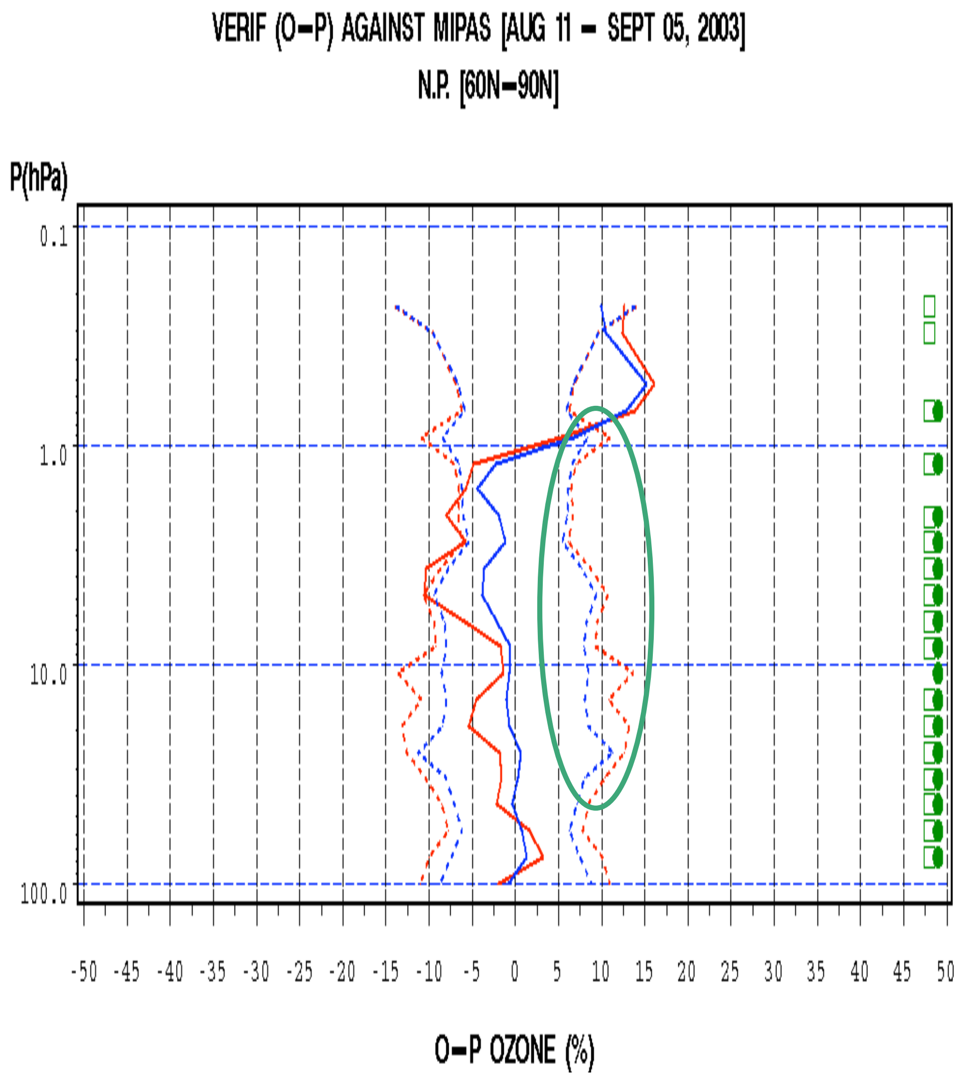

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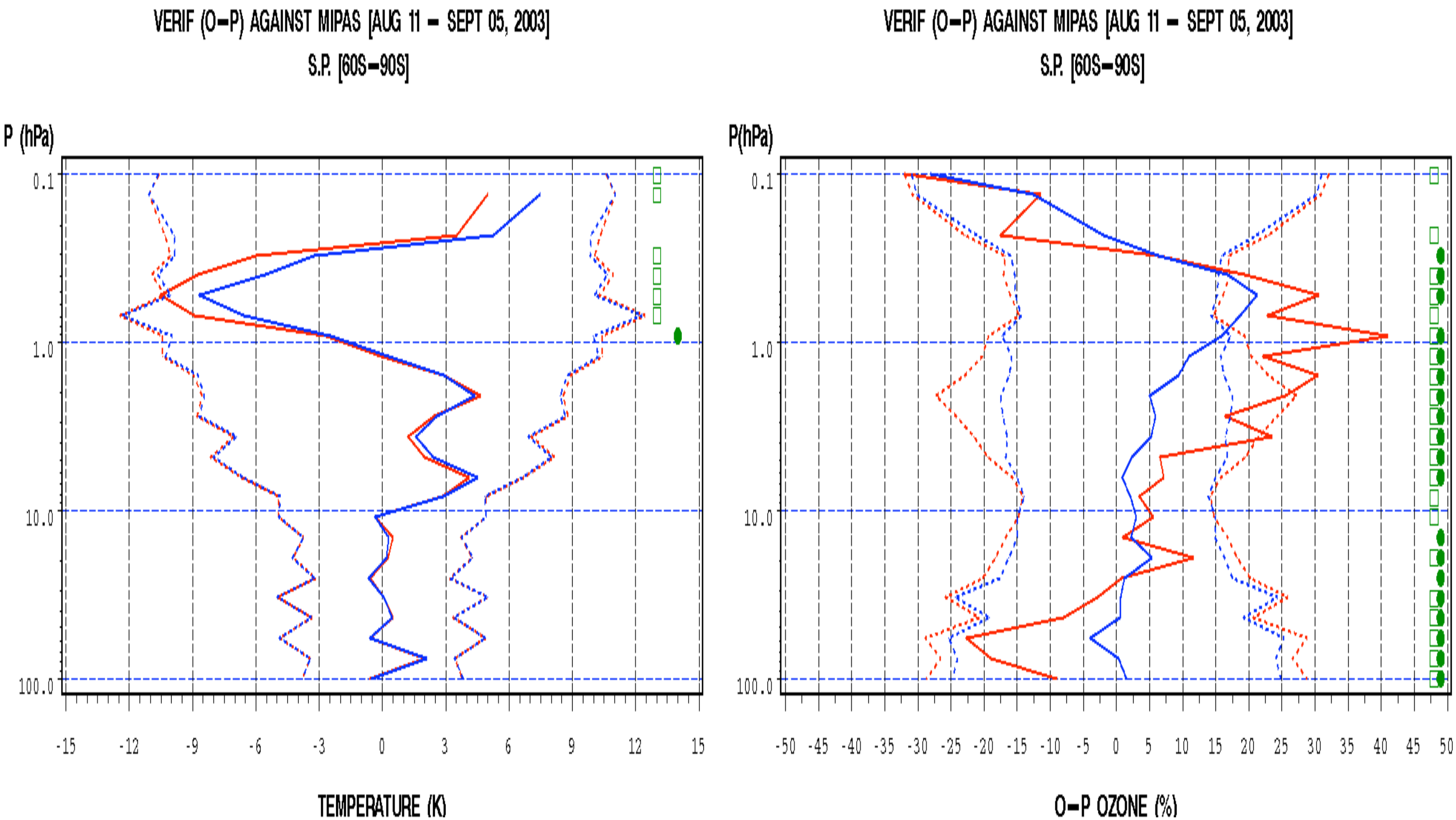
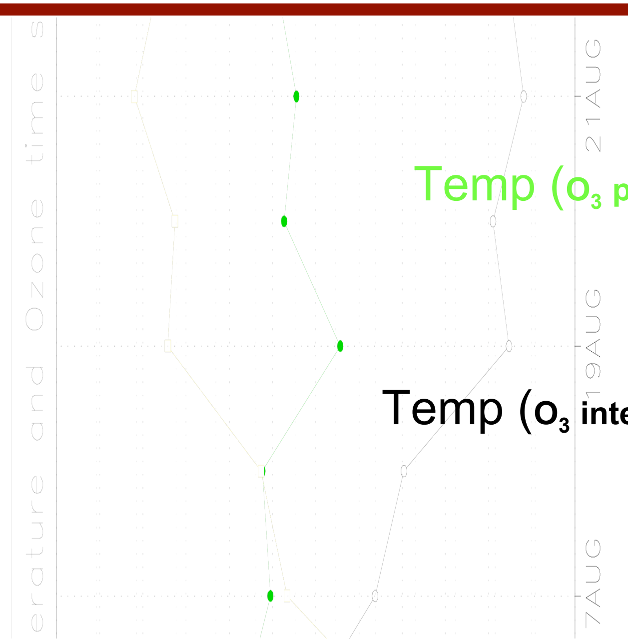


Ozone-radiation interaction in assimilation with GEM-BIRA



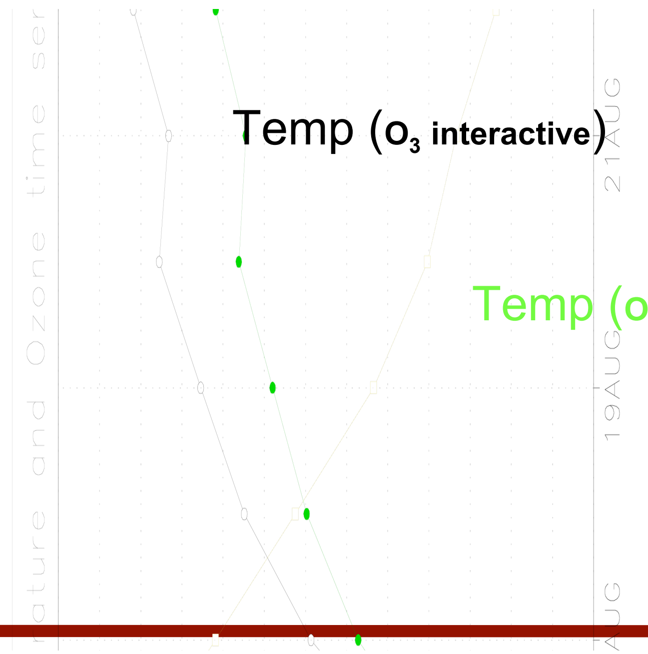
Ozone (interactive)

Temp (o_3 prescribed)

Tropics

Temp (o_3 interactive)

(ppmv) (K)



Temp (o_3 interactive)

Temp (o_3 prescribed)

Tropics

Ozone (interactive)

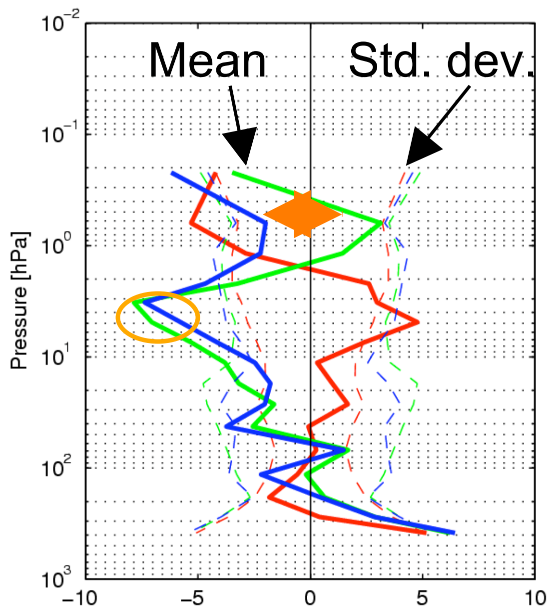
¬ Sample free model run temperature bias and std. dev. relative to MIPAS

ECMWF anal.

Free model with

interactive O3,

climate O3



12-21 Oct 2003

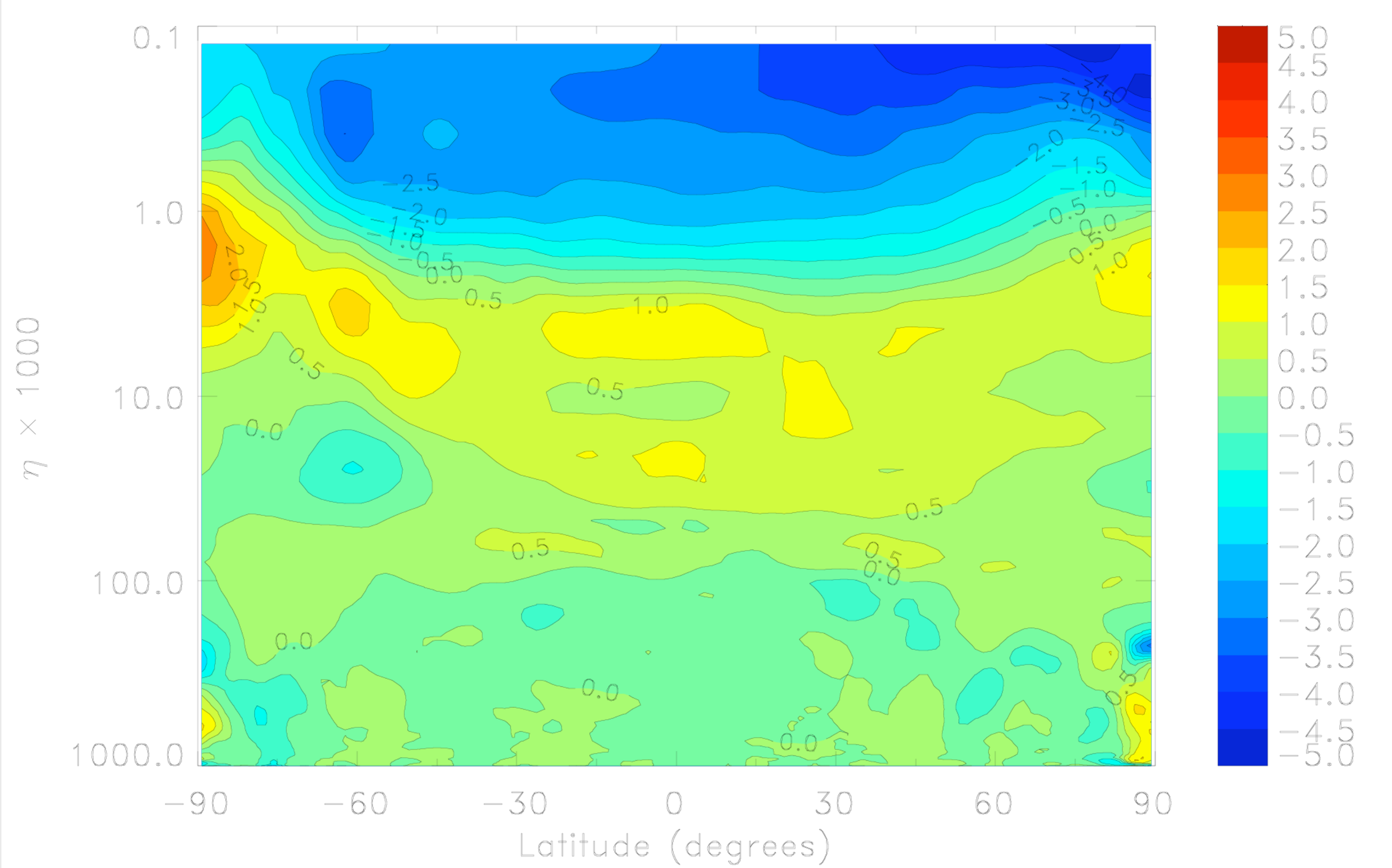
within ± 10° lat.

Obs – model field

Temperature differences of 10 day forecasts with and without radiative feedback

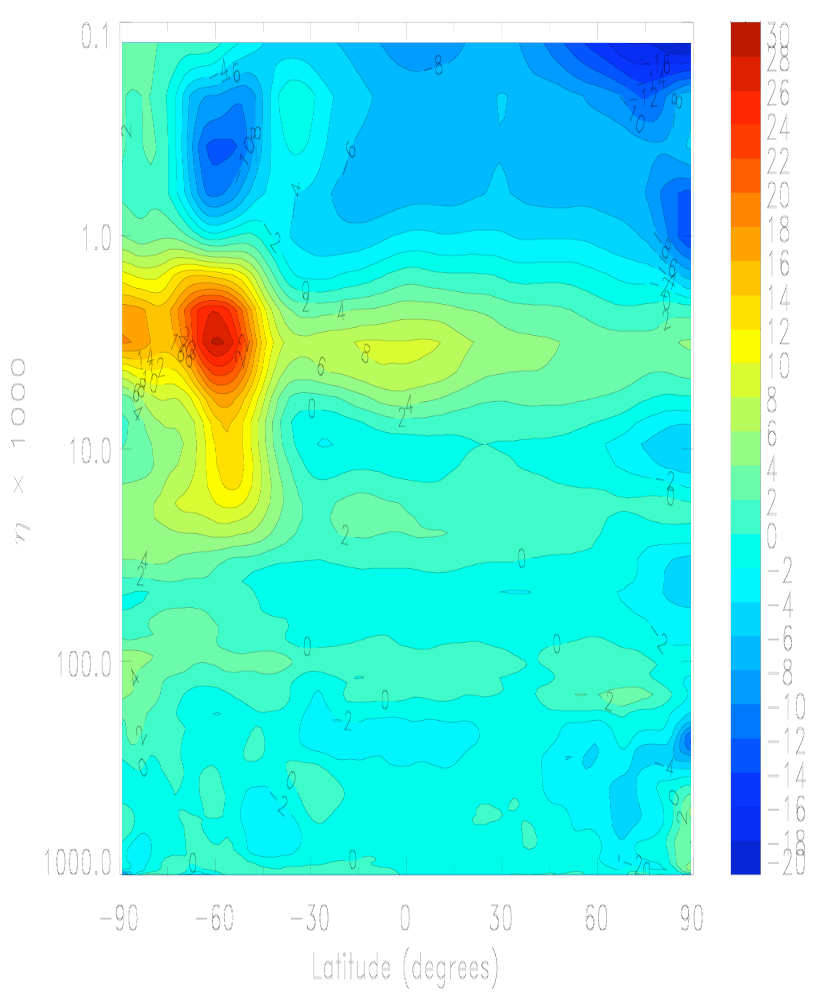
(analysis date: 12 Aug. 2003)

T (interactive O_3) – T (climatology O_3)

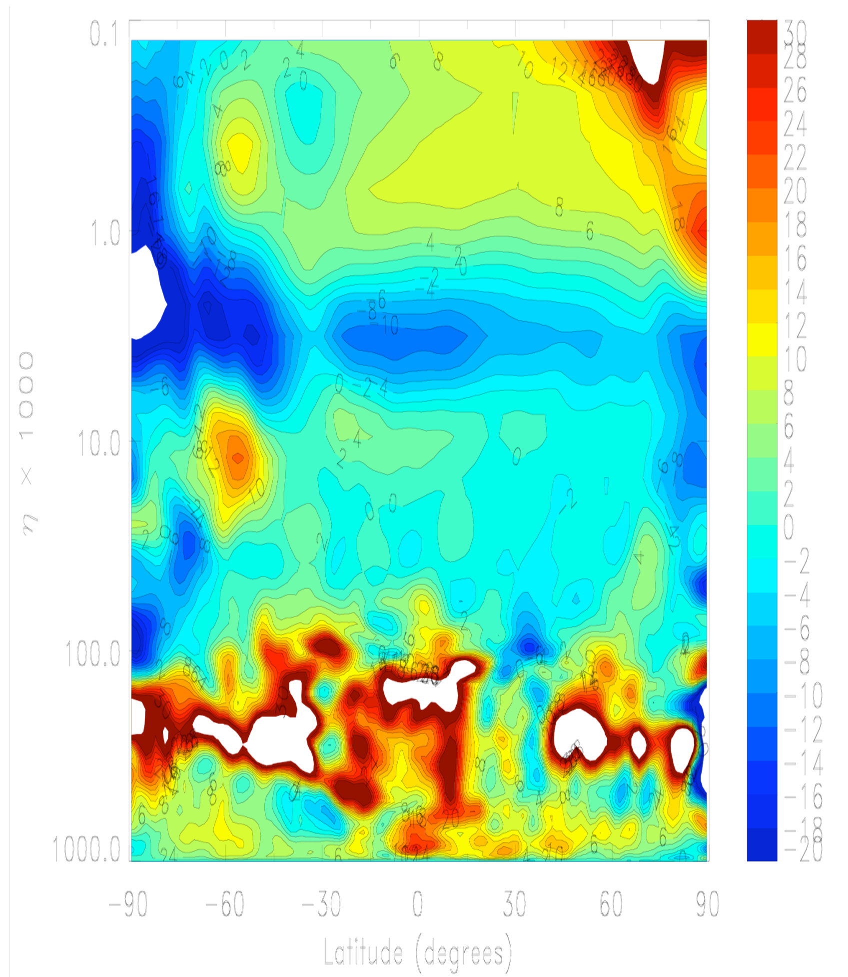


Change after a 10 day forecast with radiative feedback (final – initial)
(analysis date: 12 Aug. 2003)

Temperature change



Ozone change (%)



Conclusion

- The assimilation of the AMSU-A stratospheric channels produces significant biases in the stratospheric analyses – but no bias correction not ideal either…
- MIPAS retrieved obs. bias above 1hPa …
- Little change ozone 6-hr forecasts driven by temperature assimilation (not much T change in 6 hours).
- Larger changes in T 6-hr forecasts driven by ozone assimilation. However, correlation between T and O_3 changes is negative when O_3 is the forced parameter?
- Large model ozone biases for polar night. Results indicate a significant negative ozone bias of about 10%-25% in the upper stratophere – lower mesosphere.
-
    - The assimilation/verification of ozone precursors will be useful for identifying the source of these biases (N_2O, CFCs)
    - Is it instead a transport issue?
- The overall impact of ozone assimilation in the tropical region is generally small and becomes more significant (for std. dev.) in the polar regions where photochemistry is less active.
- The stratospheric analyses appear far from the model's radiative-photochemical equilibrium (which also has biases).
- The launching of 10-days forecast from analyses suggests a drift in terms of ozone and temperature throughout the period towards the model radiative-photochemical equilibrium (different states for interactive vs non-interactive)

Very near future plans

- Experiments to be repeated after at least:
  - removal of AMSU-A bias
  - improving meteorological and ozone constituent background error covariances.
- Investigation of possible contributions of other biases (for ozone and temperature) to proceed in parallel.
- Investigate impact of T – O_3 multivariate analysis
- Extend analysis of results…. (heating rates, vertical motion - transport)