Ozone assimilation and its impact on temperature forecasting

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SUMMARY: The development of coupled Chemical Data Assimilation (CDA) systems for UV index forecasting applications provides an opportunity to evaluate the benefit of ozone assimilation for improving Numerical Weather Prediction (NWP). Results from ozone interactive experiments using the ECCC GEM NWP model show indeed that the implementation of prognostic ozone for the computation of radiative heating has a significant impact on the temperature distribution throughout the stratosphere and upper troposphere regions. This study presents an overview of the various issues associated with the incorporation of radiative feedbacks from a prognostic ozone scheme in the ECCC global NWP system.

The coupled Chemical Data Assimilation (CDA) system with on-line linearized stratospheric chemistry

Numerical Weather Prediction (NWP) model: **The Operational Global Environmental Multiscale (GEM) model**

- **Semi-Lagrangian and Semi-implicit time discretization**
- **80 vertical levels; lid at 0.1 hPa.**
- **CDA experiments performed on a uniform 800x600 longitude-latitude grid**
- **Sensitivity experiments done at 1 degree resolution on a Yin-Yang grid system.**

Global incremental assimilations: **Done over successive 6hr intervals using the 3D-VAR/FGAT scheme.**

- **Background error correlations are horizontally isotropic and homogeneous with vertical and horizontal correlations being non-separable for all variables except for ozone..**
- **Meteorological fields during the ozone assimilation runs are refreshed every 6 hours from GEM weather analyses.**
- **Assimilated ozone data: GOME-2 total column amounts (MetOp; EUMETSAT) and MLS ozone profiles**

On-line interactive chemistry module : **The LINOZ linearized chemistry scheme**

$$\frac{\partial q}{\partial t}=(P-L)+\frac{\partial (P-L)}{\partial q}(q-q^o)+\frac{\partial (P-L)}{\partial T}(T-T^o)+\frac{\partial (P-L)}{\partial C_{O_3}}(C_{o_3}-C^o_{o_3})$$

q is the ozone volume mixing ratio, T is the temperature, C_{O3} is the column ozone above the model level, P and L are the production and loss terms and q_o ,T_o and C^o_{o3} are climatological parameters (de Grandpré et al., 2016). The partial derivatives coefficients have been pre-computed using a photochemical box model (McLinden et al., 2000). Below 400 hPa, the ozone distribution is forced toward climatological values with a 48 hr relaxation timescale.

Version 1 : Ozone climatology (q^o) taken from McPeters et al. (1993)

Version 2 : Ozone climatology (q^o) taken from Fortuin and Kelder (1998) as in the GEM NWP model

1-year sensitivity experiments using the chemically coupled GEM NWP model

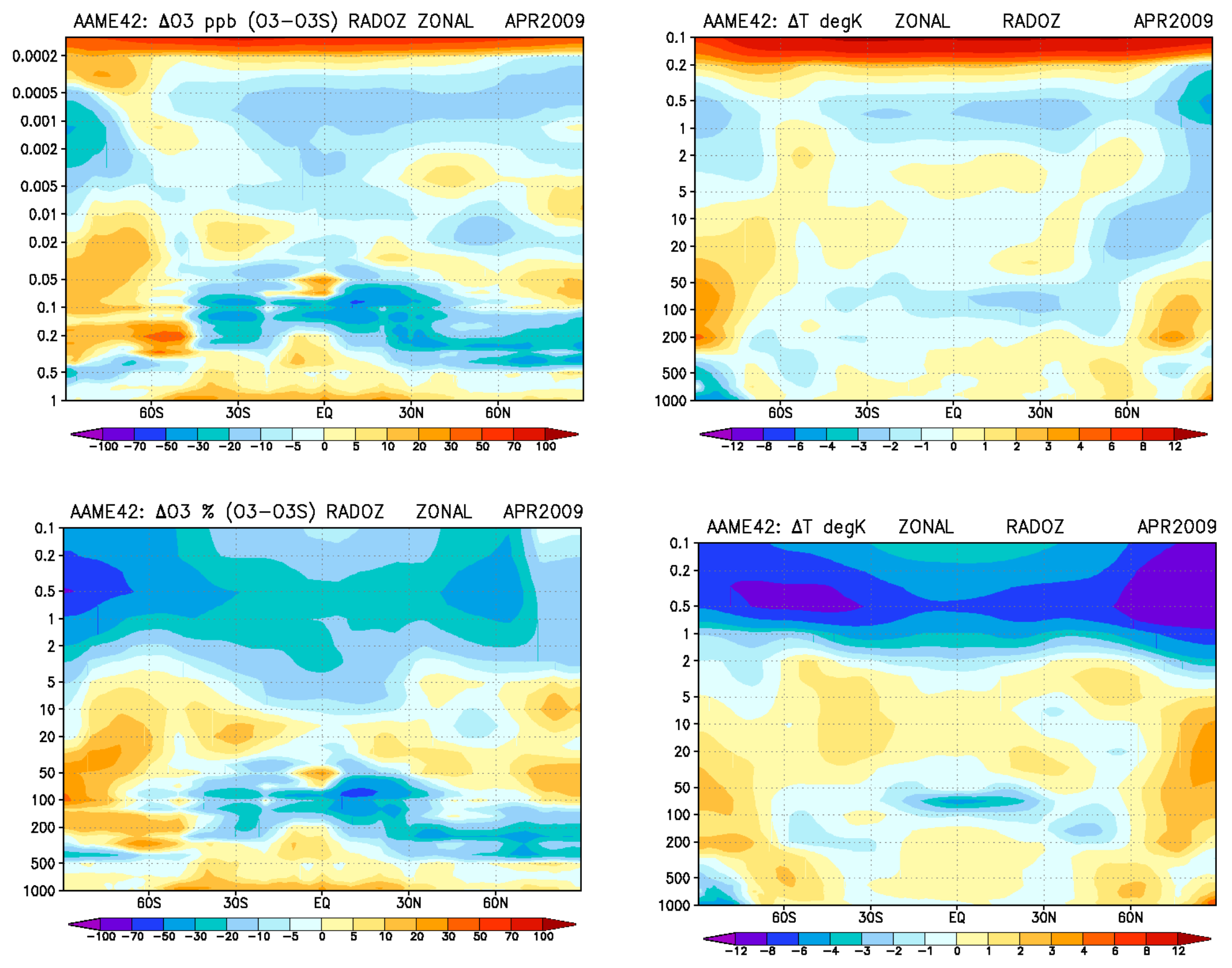

Fig 1. Monthly mean ozone and temperature differences in April between interactive and non-interactive experiments using LINOZ-1 (top panels) and LINOZ-2 (bottom panels)

The implementation of ozone radiative feedbacks for NWP applications requires the use of an ozone model which is fast and accurate throughout the entire model domain from the surface to the lower mesosphere. Results from ozone interactive simulations on Figure 1 show the impact of using different ozone climatologies on the temperature distribution. In the case of LINOZ version 2 the ozone climatology is the same as in the GEM NWP model which prevents the development of a significant cooling near the top of the model.

Results from ozone interactive simulations using LINOZ v.2 is shown on Figure 2. Changes in the ozone distribution mostly occur in the stratopause and tropopause regions throughout the year. Ozone decrease in the upper stratosphere and lower mesosphere reduces solar heating and produces a significant cooling in the region. The use of linearized chemistry also decreases ozone in the lower stratosphere region which reduces infrared heating and produces a cooling which persists throughout the year.

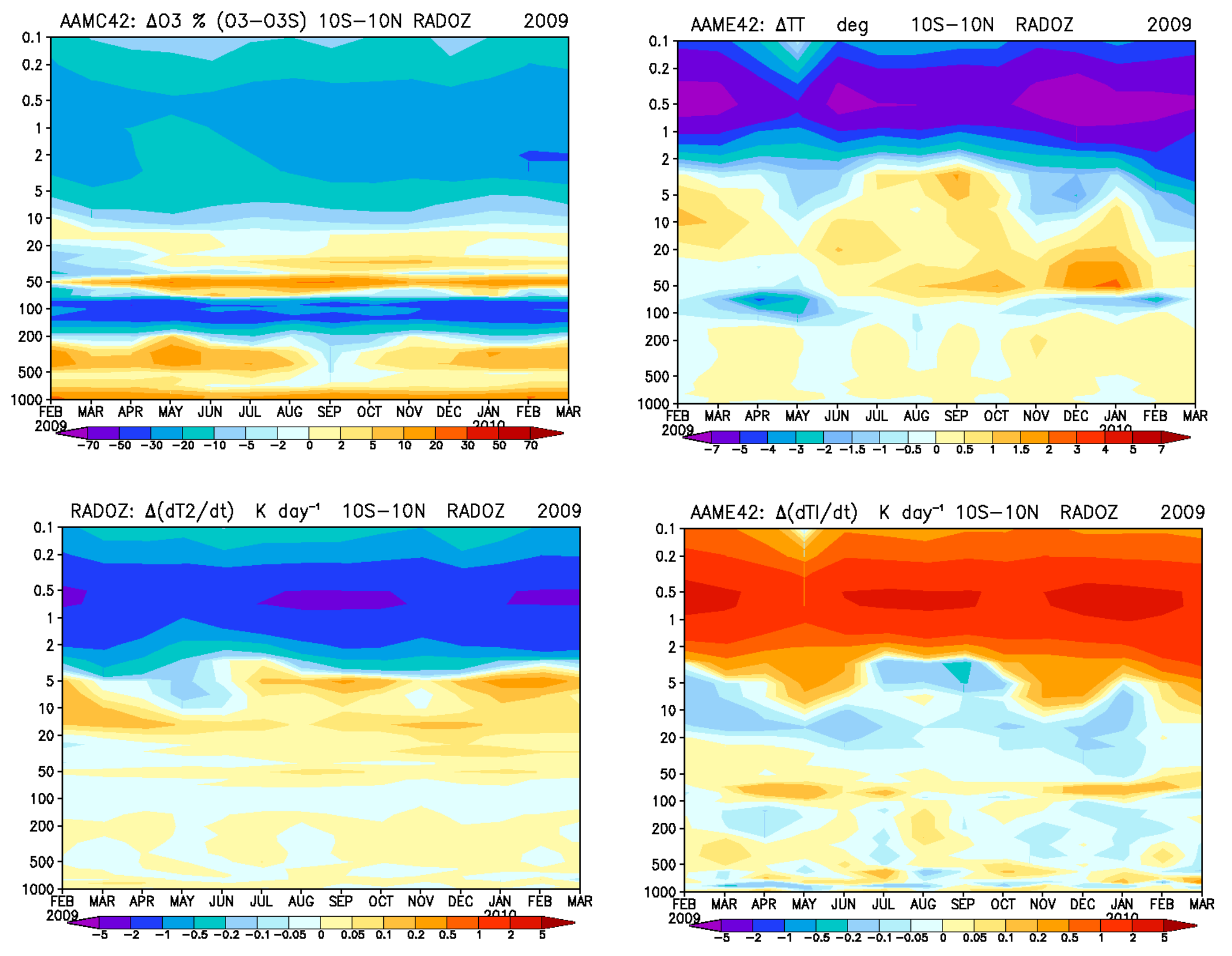

Fig 2. Time series of ozone and temperature differences (top panels) in tropics between interactive and non-interactive experiments using LINOZ v.2. Timeseries of shortwave and Longwave radiative forcing (K/day) are shown in bottom panels.

Coupled Chemical Data Assimilation and forecasting experiments

The impact of incorporating prognostic ozone radiative feedback on temperature analyses and forecasts has been evaluated by performing an assimilation cycle in which both meteorological and chemical measurements are assimilated. Results obtained from this coupled DAS are compared with a non-interactive control experiment. An ensemble of interactive and non-interactive forecasts have been launched every 12 hours during the winter 2009 period for evaluating its impact on medium range temperature forecast. Forecasts have been compared against analyses and in-situ observations in different regions in terms of biases, RMS errors and anomaly correlations.

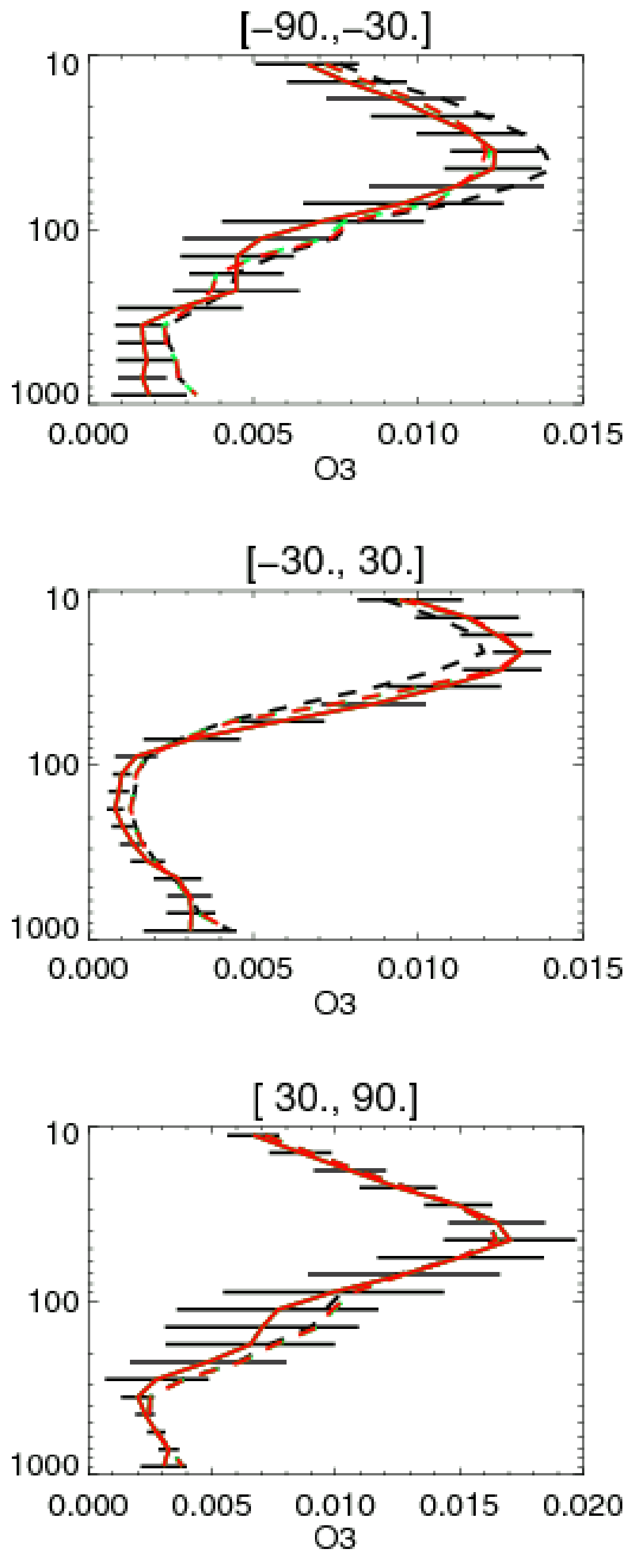

Fig 3. January-February time means in partial pressure (Pa) from ozonesones (solid;red) and ozone analyses (dashed). The horizontal bars denote the variability standard deviations of the ozonesonde data.

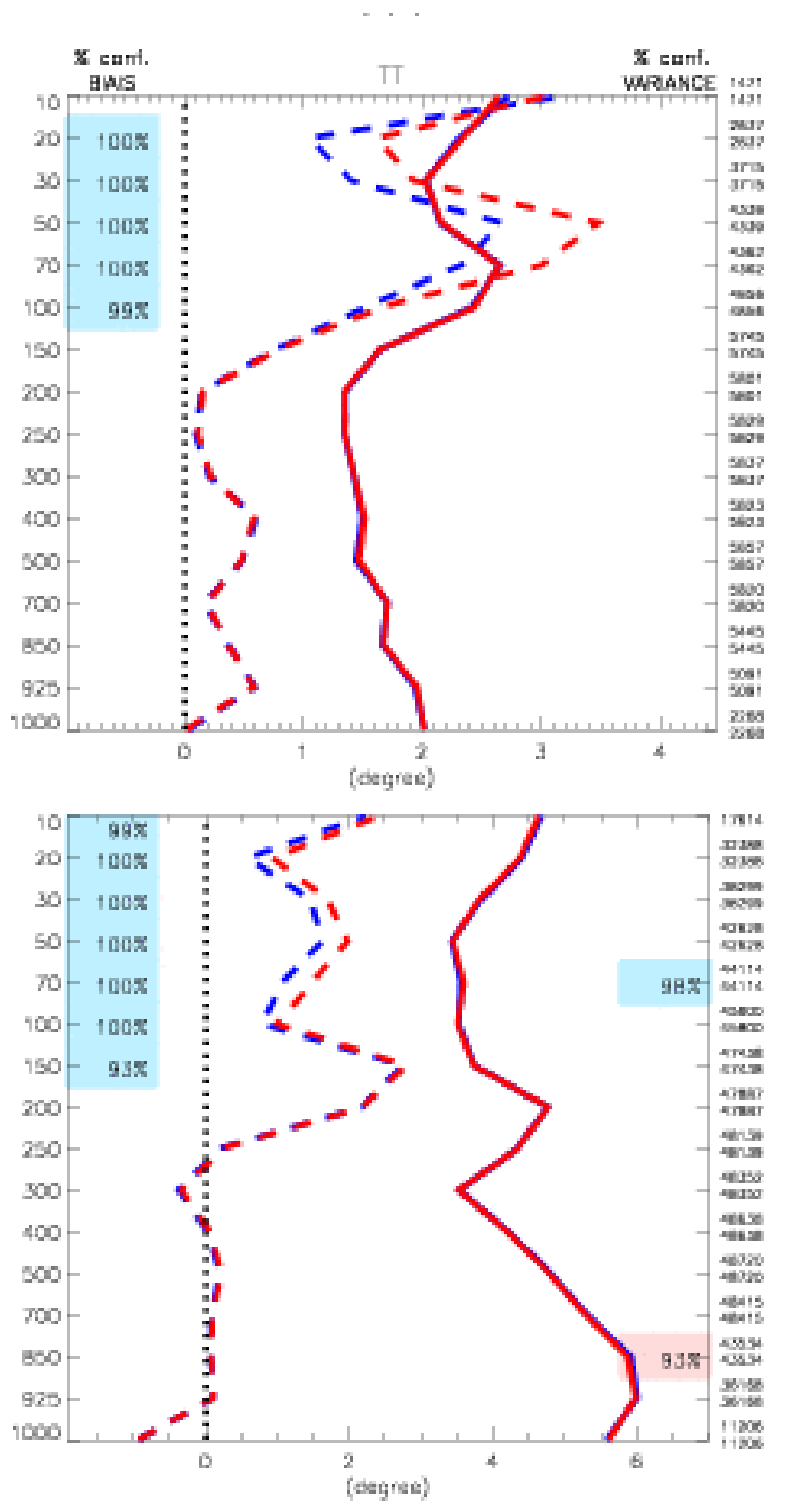

Fig 4. Observation minus 240-hr temperature forecast (O-F) mean differences (solid) and standard deviations (dashed) in the tropics (top) and global domain (bottom) against radiosondes for the period Jan 1st to Feb 28th 2009. Difference from non-interactive (blue) and interactive (red) ensemble ozone forecasts.

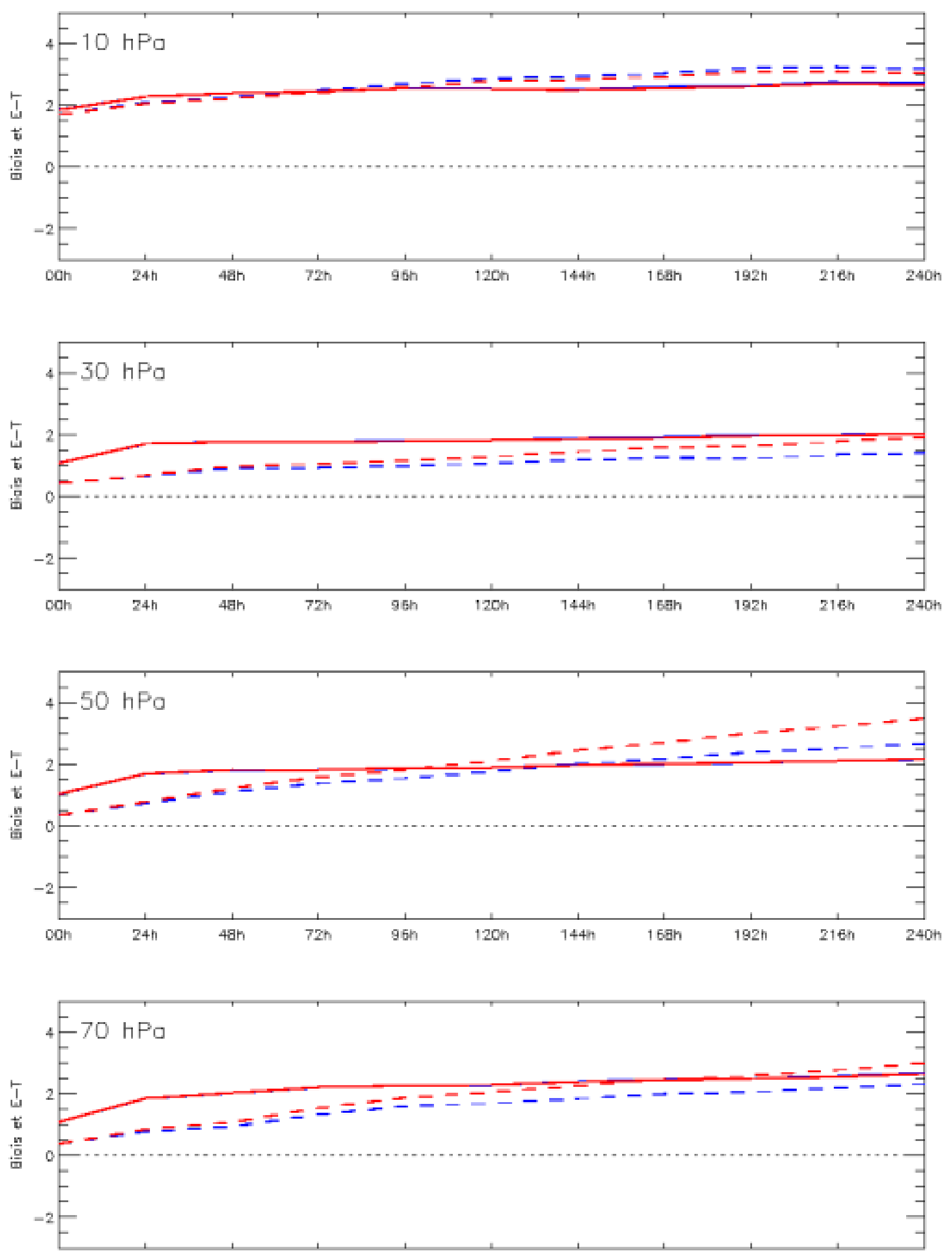

Fig 5. Time series of radiosonde observations minus forecast (O-F) mean temperature differences (solid) and standard deviations (dashed) for the period Jan 1st to Feb 28th 2009 at 10, 30, 50 and 70 hPa in the tropics [20S-20N]. Results from non-interactive (blue) and interactive (red) ensemble ozone forecasts.

Ozone forecasting and evaluation against meteorological and chemical analyses

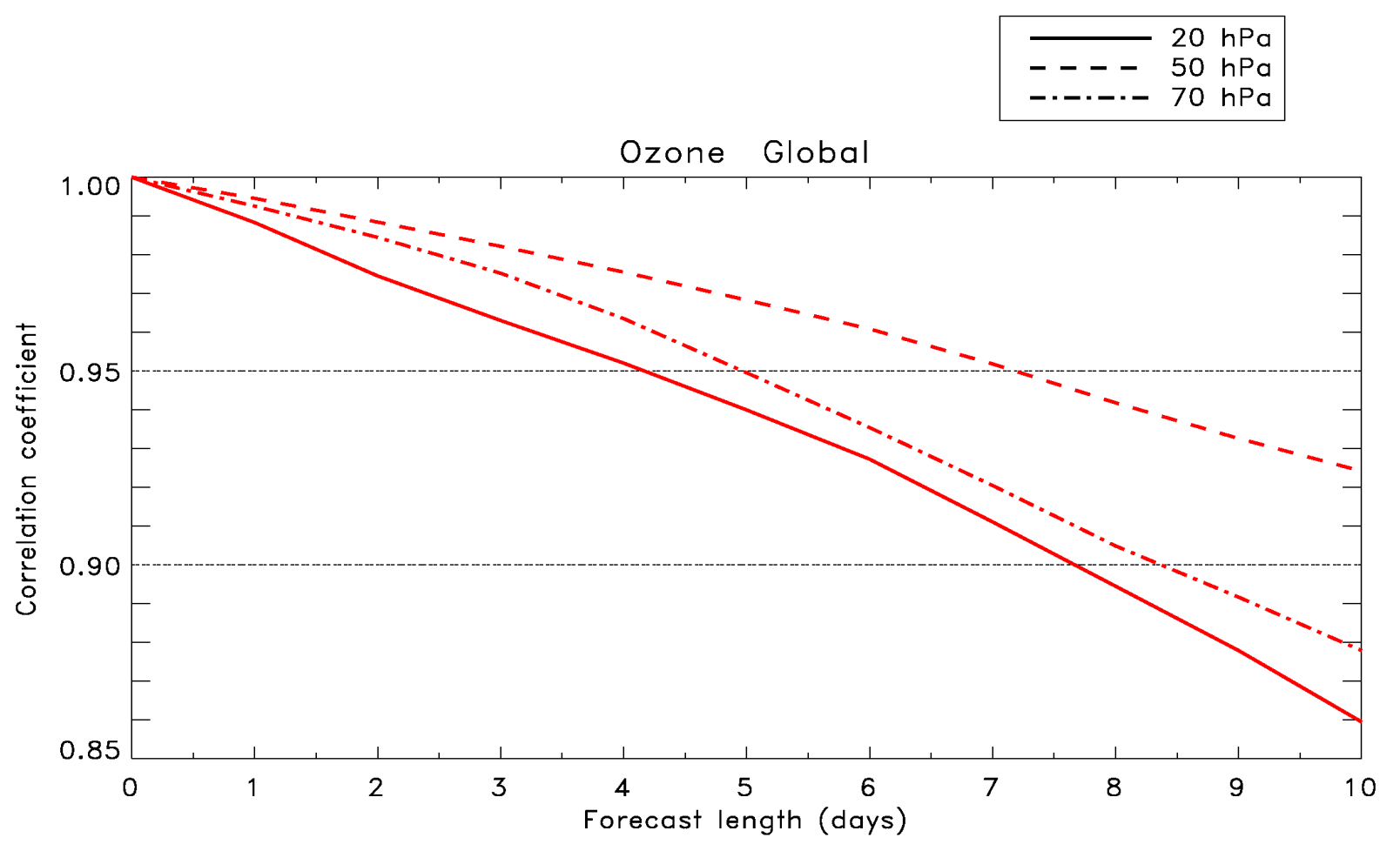

Fig 6. Ozone anomaly correlation at 20 haP (solid), 50 hPa (dashed) and 200 hPa (short and long dashed) for 1 month summertime conditions.

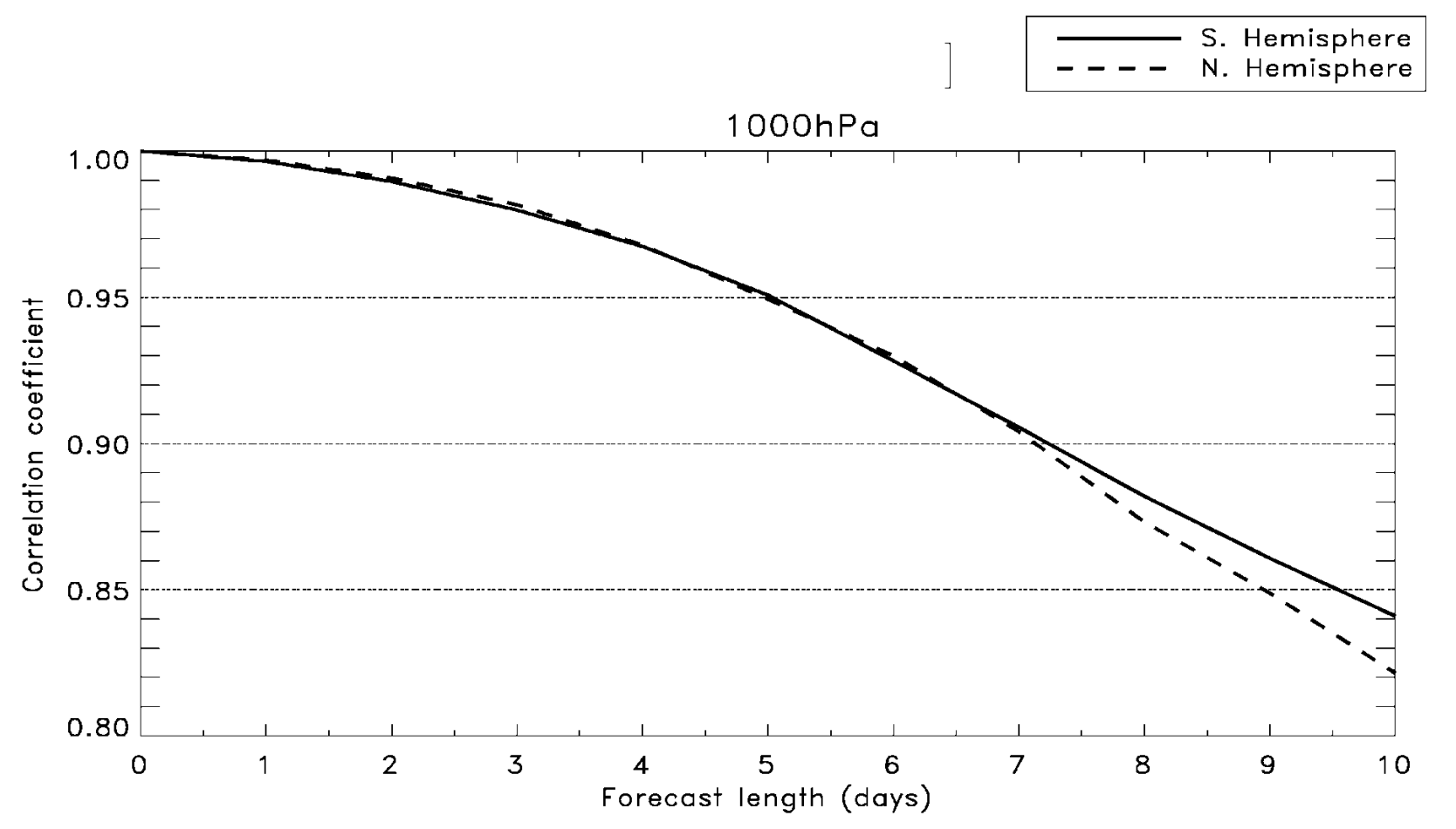

Fig 7. Column ozone anomaly correlation for summertime conditions.

The comparison against radiosonde measurements on figures 3,4,5 shows that ozone interactive forecasts are significantly colder than non-interactive forecasts which contributes to the enhancement of a model cold bias in the lower stratosphere region with a maximum impact near 50 hPa. The comparison against analyses on Figures 6 and 7 shows that the ozone predictability reaches several weeks and maximizes in the lower stratosphere. Results on Figure 8 also show an improvement in the temperature predictability within the lower stratosphere with the use of an ozone interactive system.

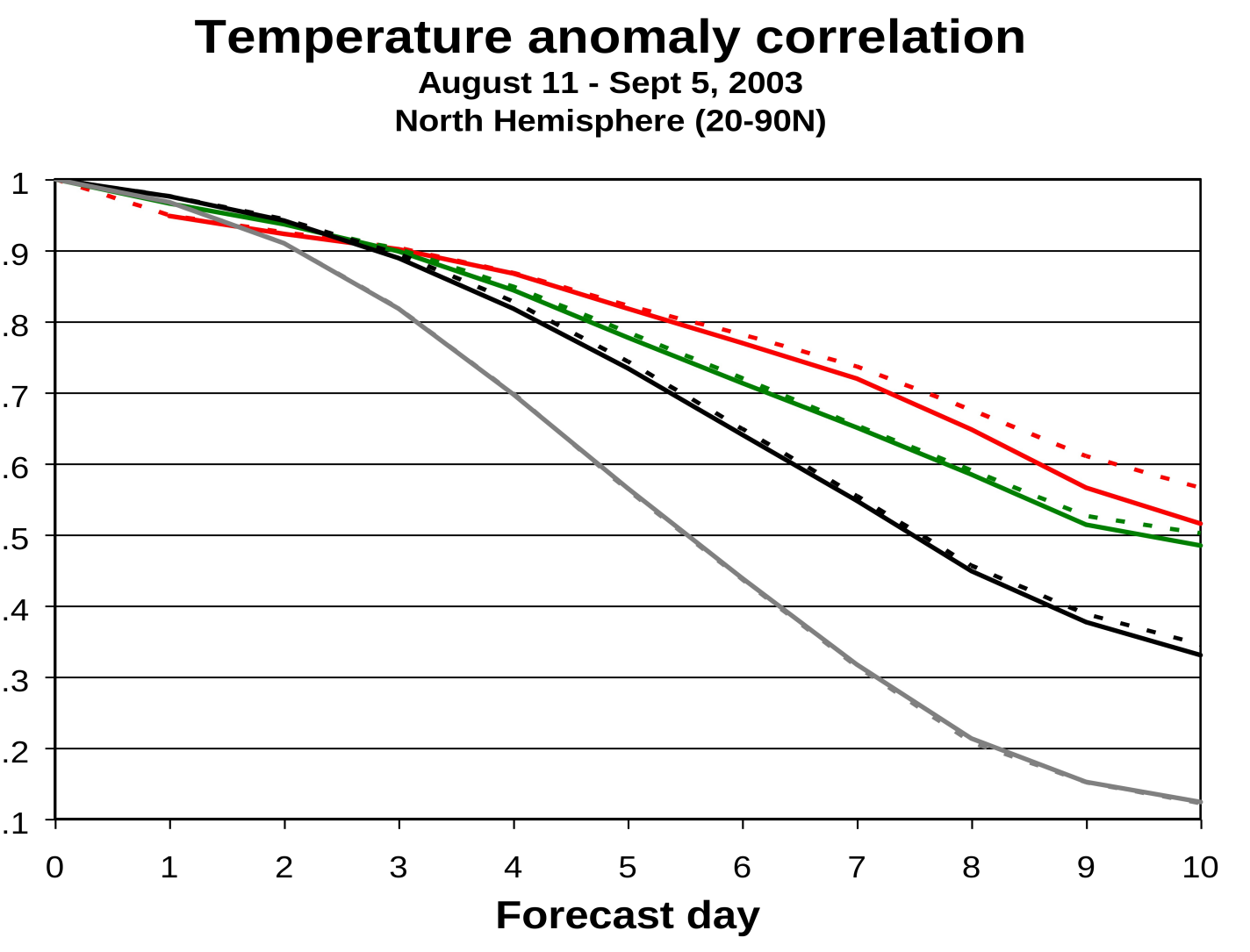

Fig 8. Temperature anomaly correlation at 50 (red), 70 (green), 100 (black) and 200 (grey) hPa for non-interactive (solid) and interactive (dashed) forecasts in the NH (20-90N) summertime conditions.