Isolating the role of different forcing agents in global stratospheric temperatures changes

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1. Introduction

Satellite observations of global stratospheric temperatures show that the stratosphere cooled at all stratospheric altitudes since 1979 with a characteristic step-like behavior. In order to isolate the role of different forcing agents in the global stratospheric temperature time series, we performed a set of simulations using the NASA Goddard Earth Observing System Chemistry-Climate Model (GEOSCCM) where we incrementally add the forcing agents acting on stratospheric temperatures. We performed the following simulation ensembles from 1979 to present (each ensemble consists of 3 members):

- SST: time-varying observed 1979-2014 SSTs and concentrations of greenhouse gases (GHG) and ozone depleting substances (ODS) fixed at 1960-levels. Volcanic eruptions are not included and the solar forcing is held constant;
- +GHG: as SST, but with increasing GHG concentrations from observations up to 2005 and from the RCP 4.5 after 2005 (Fig. 1a);
- +ODS: as +GHG, but with changing ODS concentrations (Fig. 1a+b)
- +Volc: as +ODS, but including also volcanic eruptions, specified as injection of sulfur dioxide (Fig.1a+b+c);
- +Sun: as +Volc, but also including changes in solar flux (Fig.1a+b+c+d).

We compared the model simulated temperature anomalies to observations by MSU LS (15-25km altitude) and SSU channel 3 (40-50km altitude), after being weighted with the appropriate weighting function.

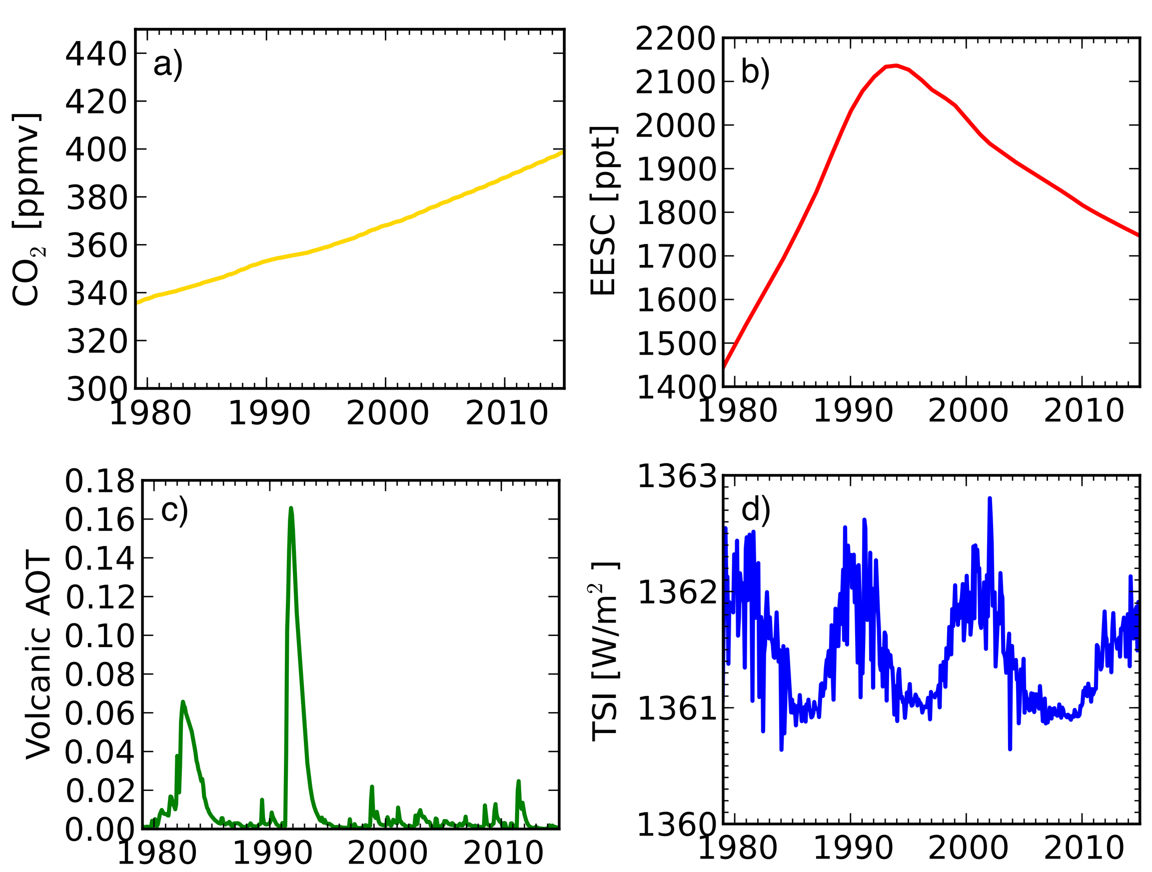

Fig.1: Forcing applied to the model simulations. a) CO2 concentrations; b) Equivalent effective stratospheric chlorine; c) Aerosol optical thickness from volcanic eruptions; d) Total solar irradiance

2. Lower stratosphere

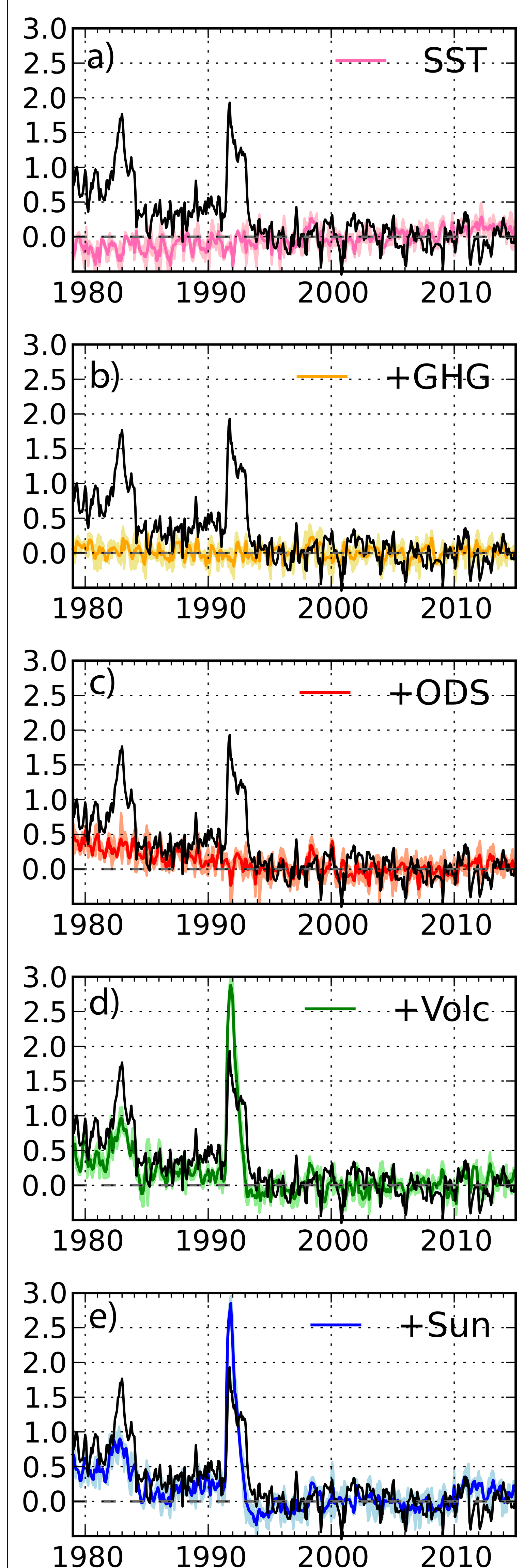

Fig.2. Near global temperature anomalies [K] with respect to the 1995-2005 monthly means. Black: observations from MSU channel 4 (15-25km altitude). Colors: GEOSCCM.

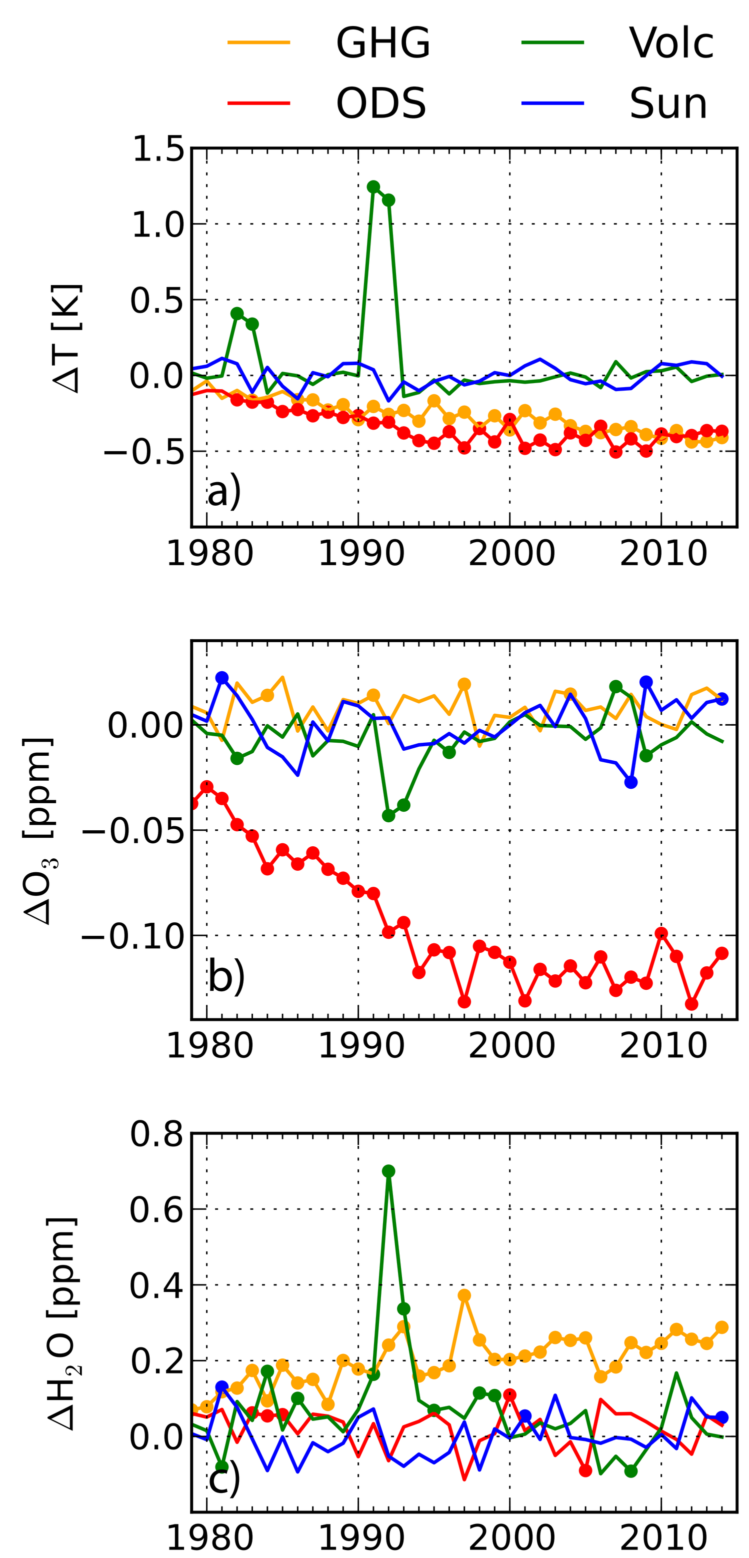

Fig.3. Changes in T, ozone, and water vapor in the lower stratosphere due to each of the forcings.

+ODS reproduces the flattening of the anomalies after the mid 1990s. The cooling from ODS stalls starting from the mid 1990s, corresponding to the slow down in ozone depletion.

3. Upper stratosphere

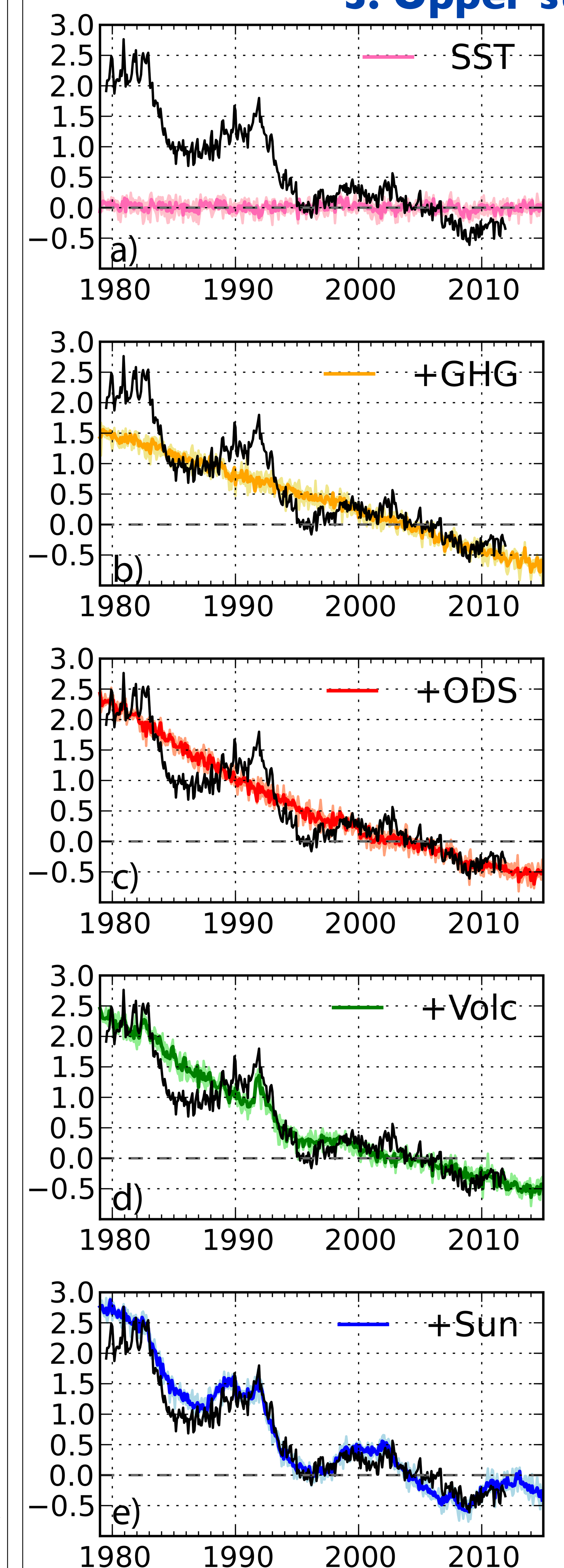

Fig.4. As Fig. 2, but for the SSU channel 3 (30-40km altitude). The step-like behavior is mainly caused by the solar cycle.

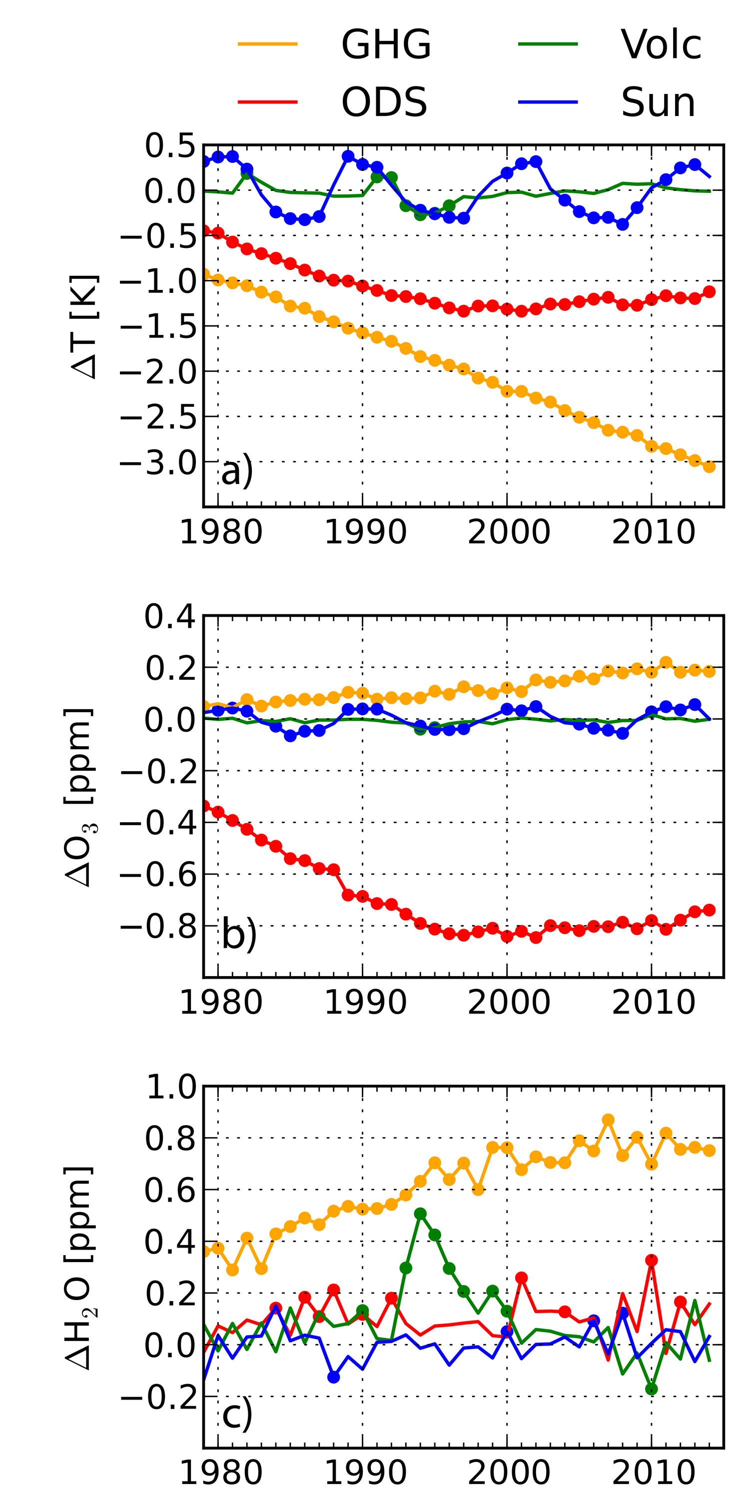

Fig 5. As Fig. 3, but for the upper stratosphere.

Mt. Pinatubo warmed the stratosphere in 1991 and 1992 and caused a cooling from 1993 to 1996 associated to an increase in water vapor. This contributed to the observed step in the mid 1990s.

4. Trends

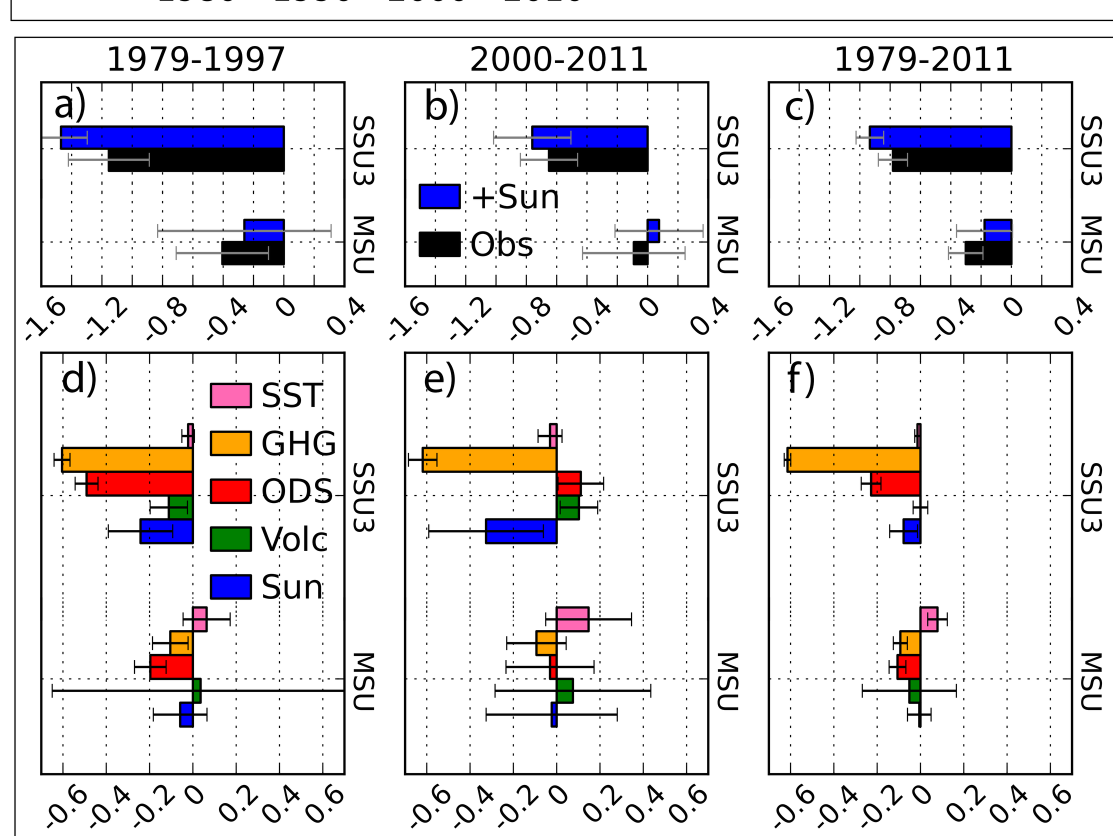

Fig.6. Upper panels: Near global temperature trends [K/decade] for the periods from Jan. 1979 to Dec. 1997, Jan. 2000 to Dec. 2011, and Jan. 1979 to Dec. 2011 in the upper (SSU3) and lower (MSU) stratosphere from observations (black) and the +Sun ensemble mean (blue). Trends are calculated using monthly mean anomalies. Lower panels: contributions of each forcing to the temperature trends. Whiskers show the 99% confidence interval.

ODS stop contributing to the cooling trend in the second half of the considered period.

5. Conclusions

- ODSs are dominate cause of long-term changes in lower stratosphere, and GHGs in the upper stratosphere (Fig. 3a, 5a, 6d-f).
- In the lower stratosphere the flattening of the temperature anomalies starting from the mid 1990s is due to the decrease in ODS concentrations following the implementation of the Montreal protocol (Fig. 2, 3).
- In the upper stratosphere the steps in global stratospheric temperature anomalies are due to the 11-year solar cycle. The 1991 eruption of Mt. Pinatubo took place during a solar maximum, and also contributed to the creation of the observed step (Fig. 3, 4).
- Temperature trends: ODSs significantly contributed to stratospheric cooling only up to the mid 1990s (Fig. 6).
- Results for the middle stratosphere (SSU channel 1 and 2) are similar to the upper stratosphere (not shown).

References: This work has been submitted to JGR in June 2015 and is currently in review. MSU data: Mears and Went (2009); SSU data: McLandress et al. (2015); SSTs: Rayner et al. (2006); GHGs: Menhausen et al. (2007); ODS: WMO (2010); Volcanic database: Diehl et al. (2012), Carn et al (2015); Solar cycle: Lean (2010).