Model Simulation of the Natural and Anthropogenic Impacts on the Variability of the Gas Composition and Temperature in the Troposphere and Stratosphere

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Atmospheric Chemical Transport Models According Their Scale

Model	Typical Domain	Resolution
Microscale	200x200x100 m	5 m
Urban	100x100x5 km	4 km
Regional	1000x1000x10 km	20 km
Synoptic	3000x3000x20 km	80 km
Global	65000x65000x20 km	$5^o x 5^o$

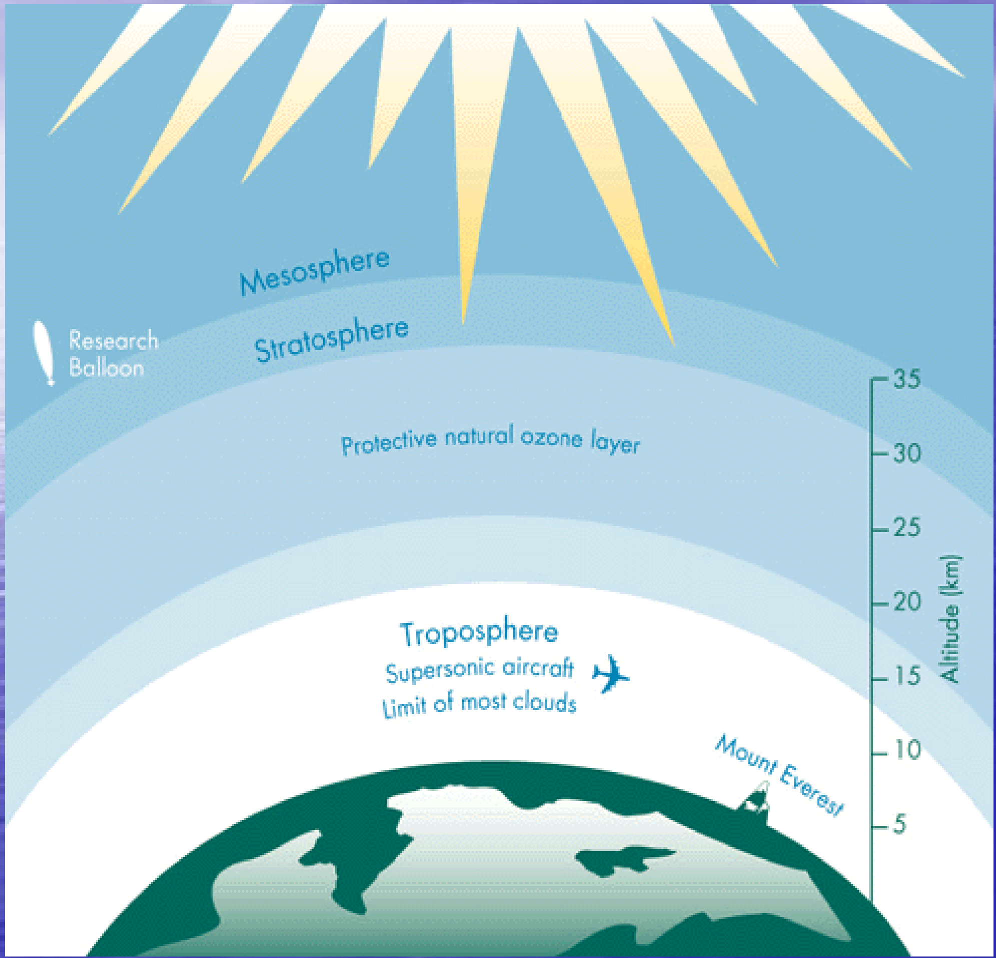
Atmospheric Chemistry Models

- **Air quality models (ACTMs) coupled with NWP models – Integrated chemical weather – NMP models**
- **Chemical transport (CTMs) combined with General Circulation Models (GCMs) – Chemistry-climate models (CCMs)**

Importance of Feedbacks

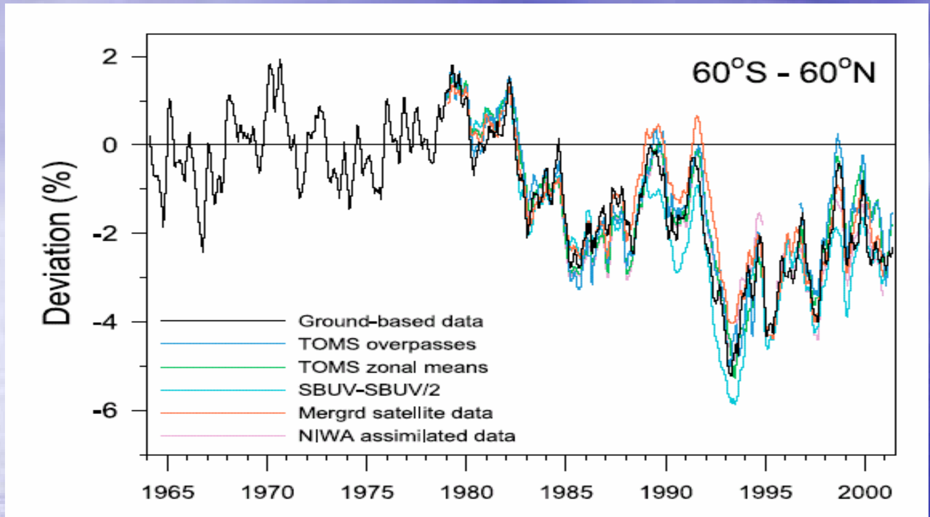
- Chemistry-dynamics-radiation feedbacks are traditionally neglected in general circulation and chemistry-transport modeling due largely to historical separation of meteorology, climate, and chemistry communities as well as our limited understanding of underlying mechanisms;
- Those feedbacks, however, are important as models accounting or not accounting for those feedbacks may give different results;
- Future climate changes may be affected by various feedback mechanisms
- Increasing evidence from field measurements have shown that such feedbacks ubiquitously exist among the Earth systems including the atmosphere, hydrosphere, lithosphere, and biosphere.

Investigation subject

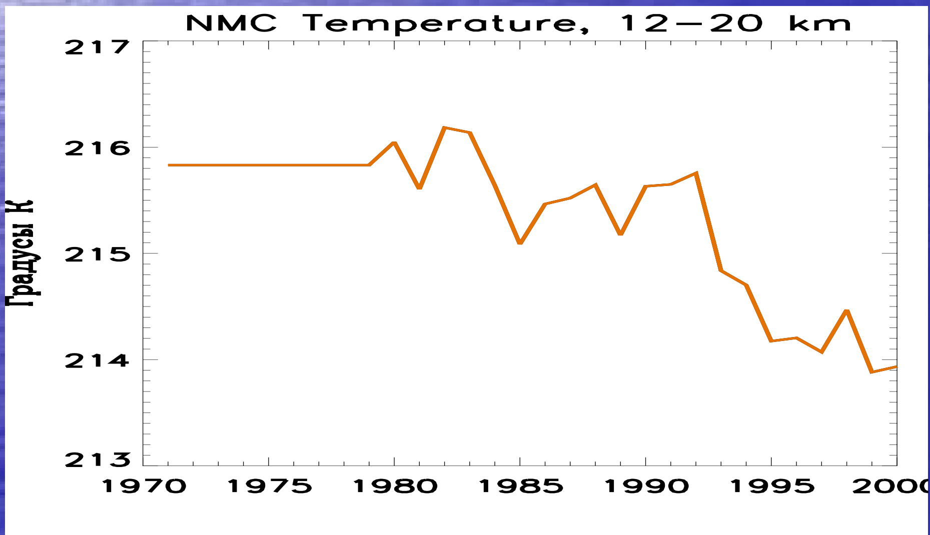


- Most of the observed long-term Ozone, other Trace Gases and Temperature Variations are attributed to the UTLS region
- Man-made and Natural factors may be responsible for this variability

Observed tendencies of ozone and temperature

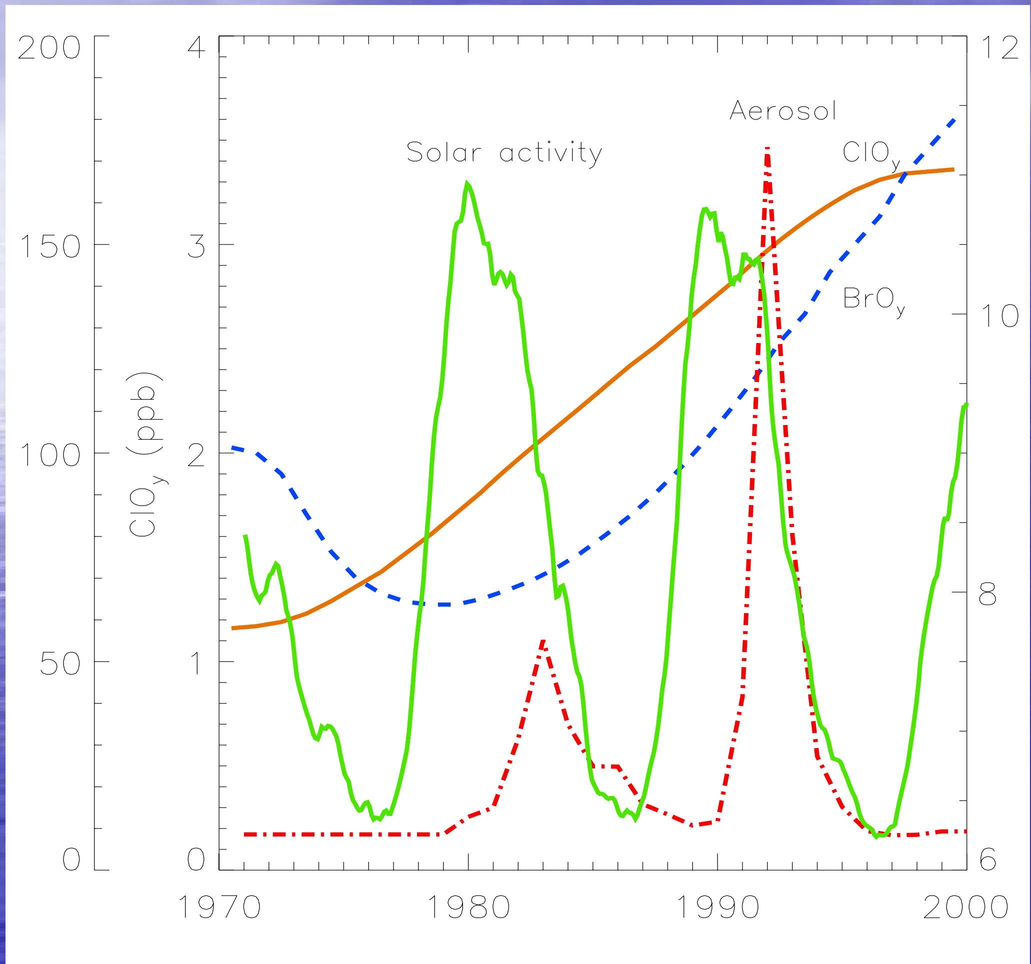


Fioletov et al. JGR (2002)



- **Stratospheric ozone depletion,**
- **Increase of concentrations of greenhouse gases and the tropospheric ozone,**
- **Global warming in the troposphere,**
- **Stratospheric cooling**

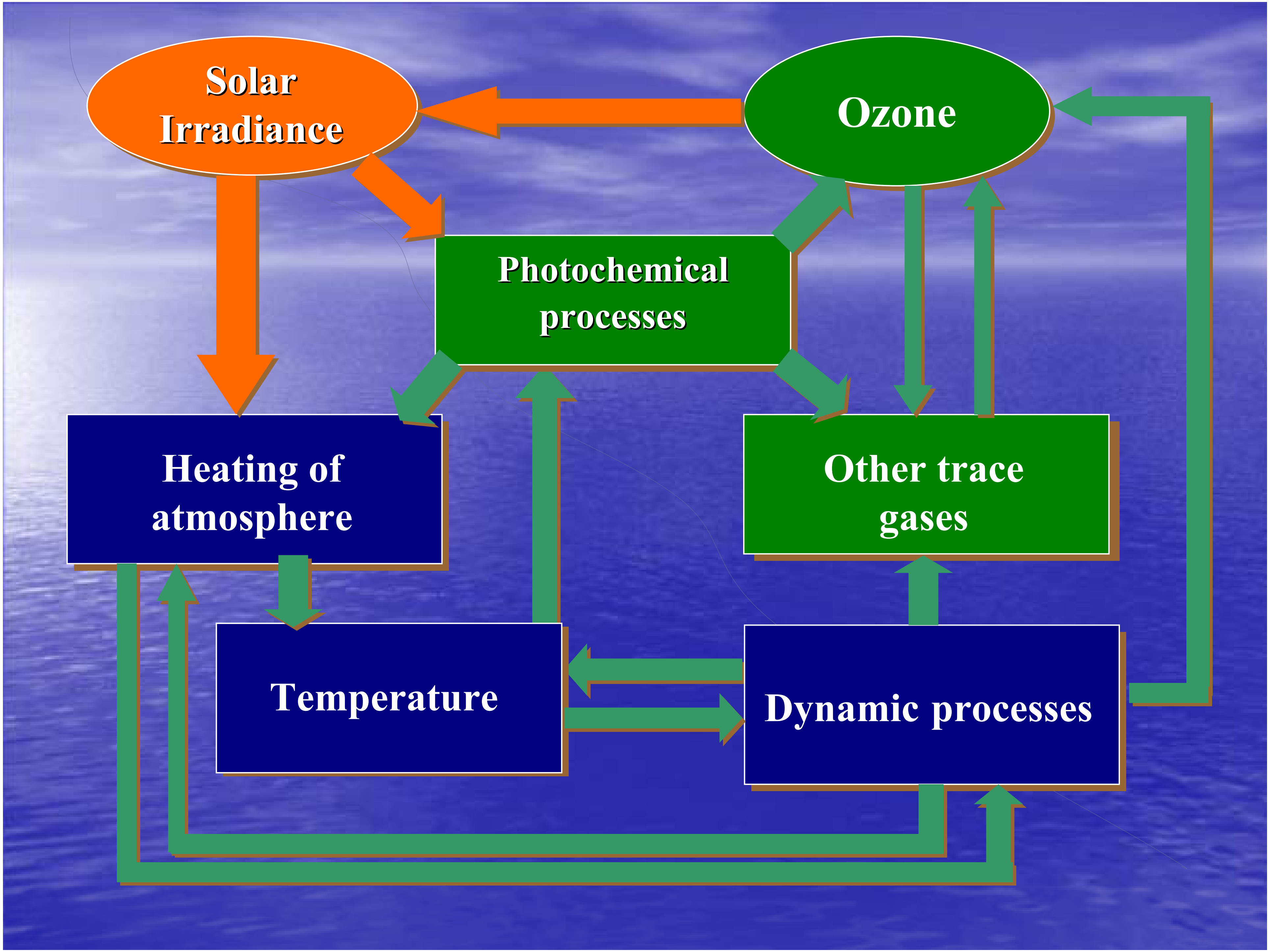
During this period:



- Stratospheric chlorine and bromine concentrations were increasing;
- Solar Activity was varying;
- Volcanoes were erupting, affecting stratospheric aerosol concentrations; and
- There were variations in stratospheric dynamics and transport.

Research Goal

- Separate natural and anthropogenic effects on the chemical composition and circulation of the Upper Troposphere and Low Stratosphere
- Test effects of feedbacks between ozone and temperature changes
- Compare to Observations


Solar Irradiance
Ozone
Photochemical processes
Heating of atmosphere
Other trace gases
Temperature
Dynamic processes

Feedbacks Included

- Heating by Ozone;
- Cooling by Water Vapor, Methane and N_2O
- Sulfur chemistry and sulfate aerosol and polar stratospheric cloud evolution;
- Chemistry feedback;
- Photolysis feedback;
- Deep and shallow convection

Polar Stratospheric Clouds

- This module is based on the combination of the thermodynamics of phase transitions and the microphysics of particle size distribution and gravity settling;
- The main assumption is that PSC particles are generated from the sulfate aerosol existing in the stratosphere as a result of absorption of nitrous oxide and water vapors;
- The resulting ternary aerosol consists of water vapor, sulfuric acid, and nitric acid

Gravitational Sedimentation

- Gravity settling is calculated depending on the particle radius and density;
- Increase in the mean radius of particles leads to increased velocities of gravity settling due to uptake of additional nitric acid;
- Denitrification and dehydration;
- Suppress nitrogen and hydrogen catalytic ozone destruction and activate chlorine and bromine catalytic destruction;

Temperature History

- If the particles at previous moment are under low-temperature conditions, the coarse aerosol can be in the solid phase;
- Under suitable thermodynamic conditions, the formation of PSCs consisting of solid nitrogen-containing particles is possible;
- If, under the same temperature conditions, the previous history of particles is not characterized by sufficiently low temperatures, the aerosol will be in the form of liquid ternary particles

STRATEGY
for Chemistry-Climate Modeling (CCM)

- **Problem of gas composition changes is studied with Chemical Transport Models (CTMs)**
- **Studies of temperature and dynamics variability are carried out using General Circulation Models (GCMs)**
- **Interaction between these models is important**

⬇

CCM

Models

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- 3-D Chemistry-Transport Model Complex SUNY-SPB (RSHU) 74 gases, 174 chemical reactions, 51 processes of photolysis, 29 heterogeneous reactions (oxygen, nitrogen, hydrogen, chlorine, bromine, carbon and sulfur families), 39 altitude levels (14 in the troposphere) (0–90 km), 5x4 horizontal resolution (88 S–88 N), polar stratospheric clouds formation and evolution

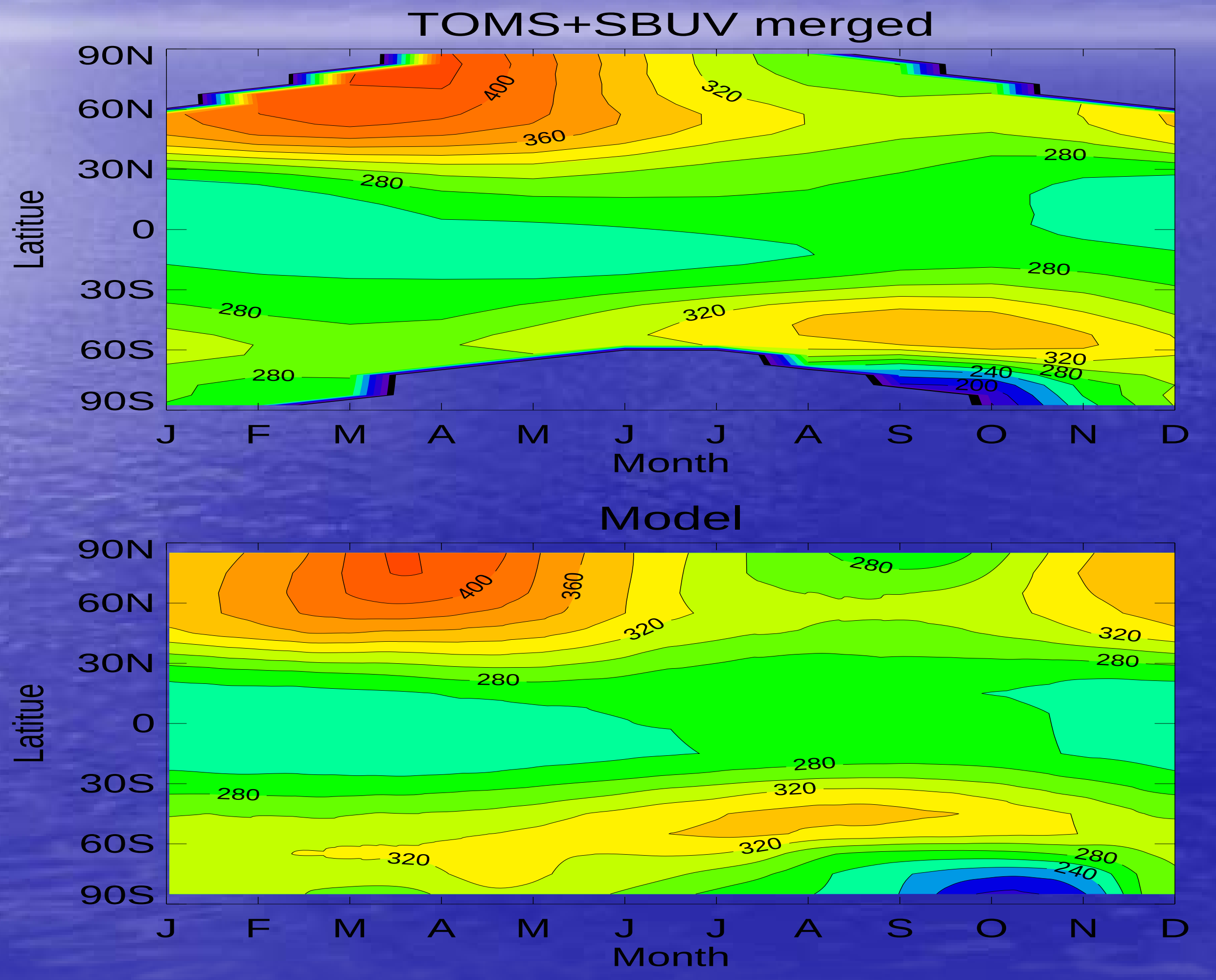
  Smyshlyaev S.P. , V.L.Dvortsov, M.A.Geller, V.Yudin, *J.Geophys.Res.,* 103, 28373-28387, 1998.

interactively coupled with

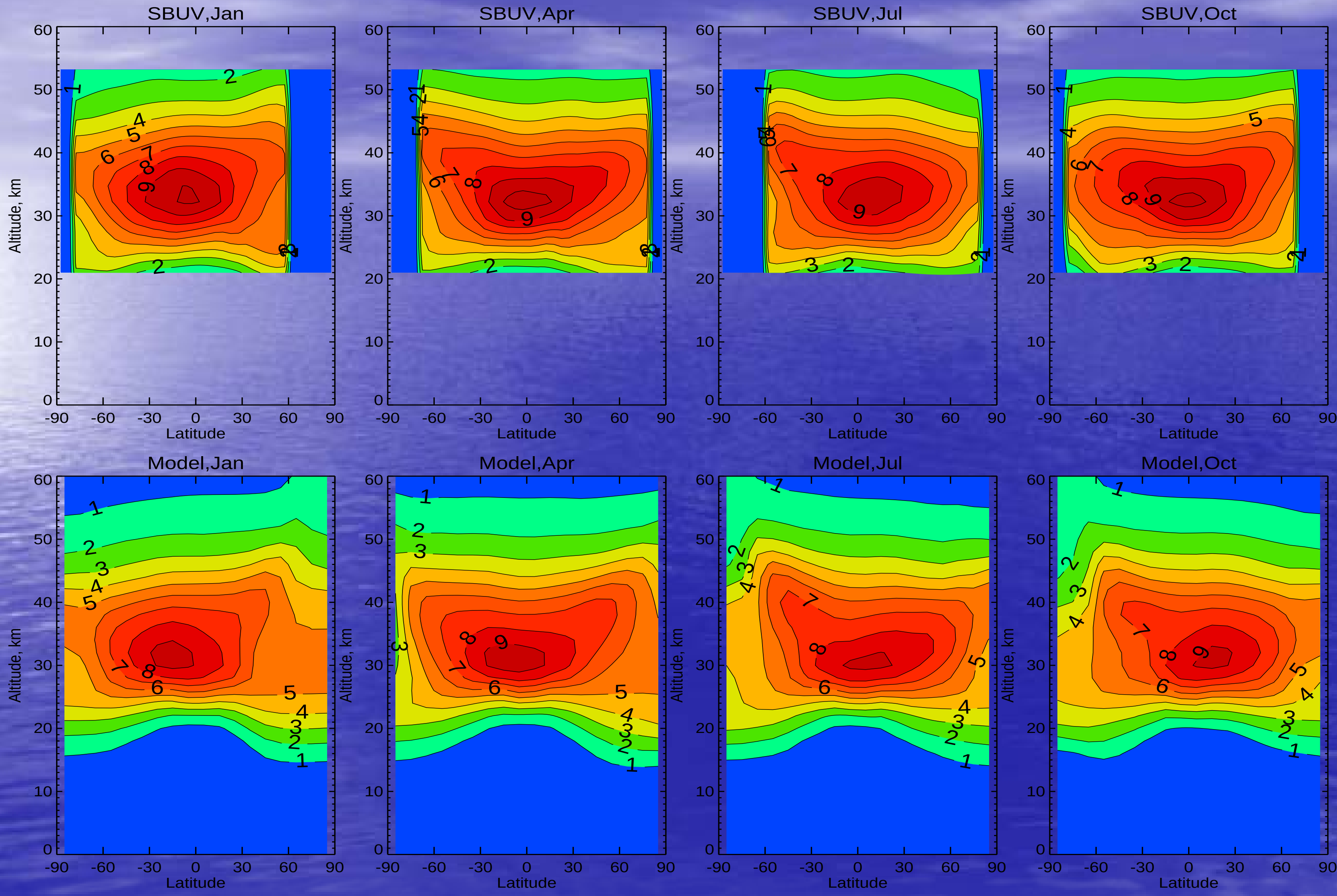
- 3-D General Circulation Model INM (Institute of Numerical Mathematics, Russian Academy of Sciences)

  V.Ya. Galin, S.P. Smyshlyaev, E.M. Volodin, "Combined Chemistry-Climate Model of the Atmosphere", Izv., Atmos. Ocean. Phys. 43, 3-17, 2007

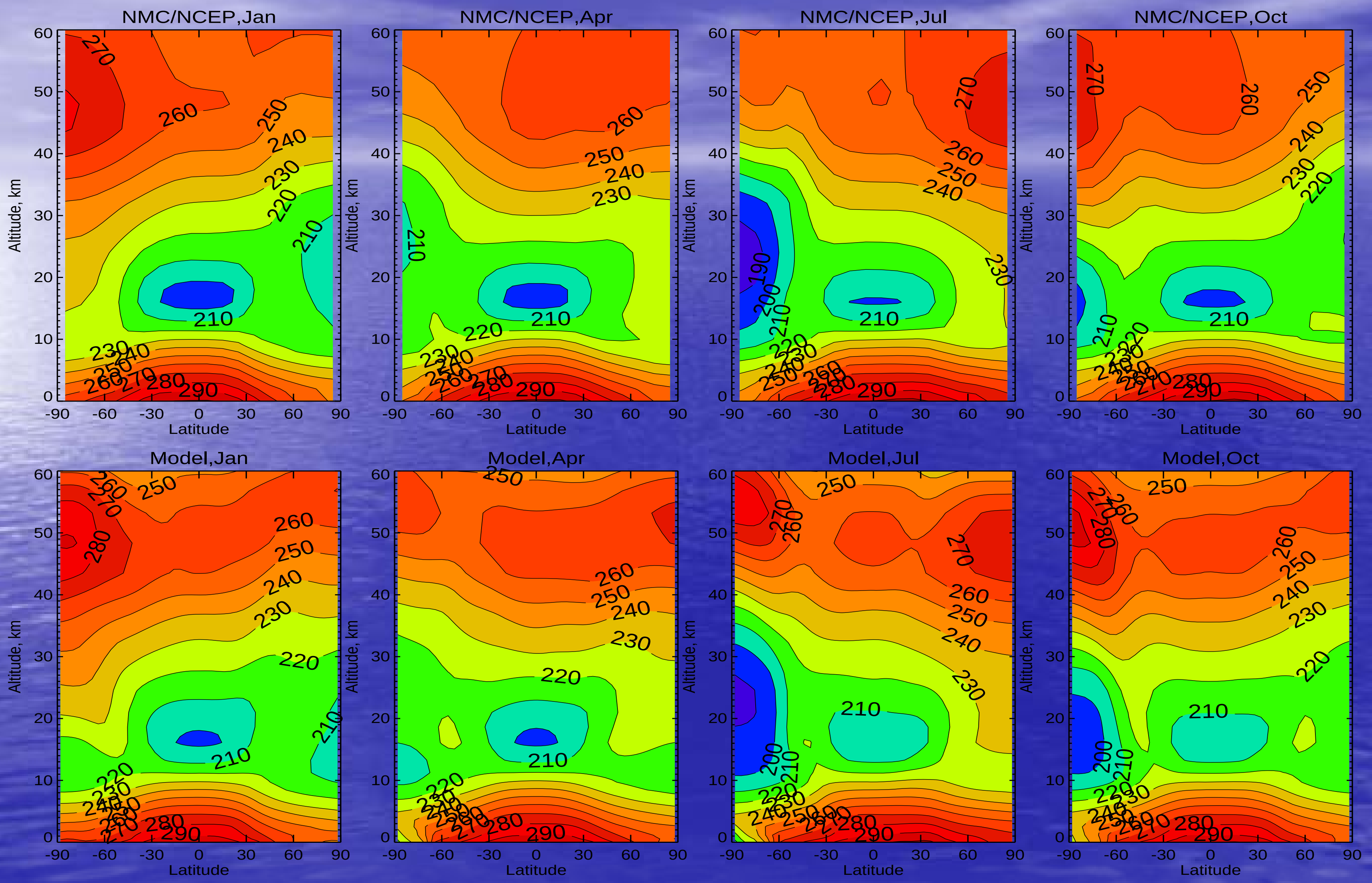
Modeled and Observed Column Ozone



Ozone altitude-latitude cross section

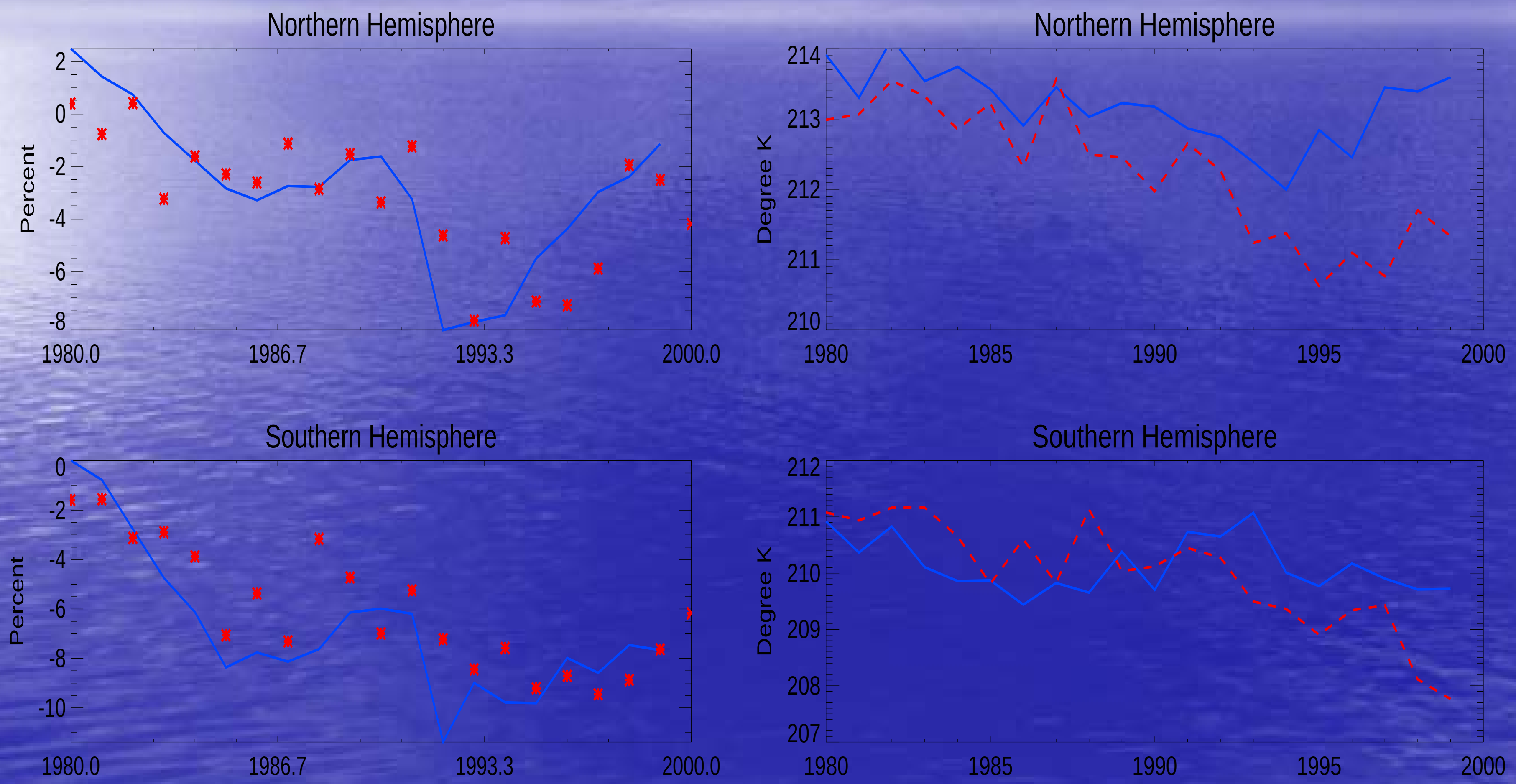


Altitude-Latitude Temperature



Long-Term Variability

- Ozone
- Temperature



Результаты химико-климатического моделирования

- Межгодовая уменьшение содержания озона в 1980-1995 годах моделируется с хорошей точностью
- Наблюдаемого сокращения содержания озона недостаточно для объяснения наблюдаемого охлаждения стратосферы
- Возможными факторами дополнительного выхолаживания стратосферы могут быть выбросы парниковых газов, которые кроме нагревания тропосферы приводят к охлаждению стратосферы и
- Изменение активности атмосферных планетарных волн и их взаимодействия со средним потоком
- Выбросы парниковых газов могут повлиять на активность планетарных волн

Methodology of numerical experiment

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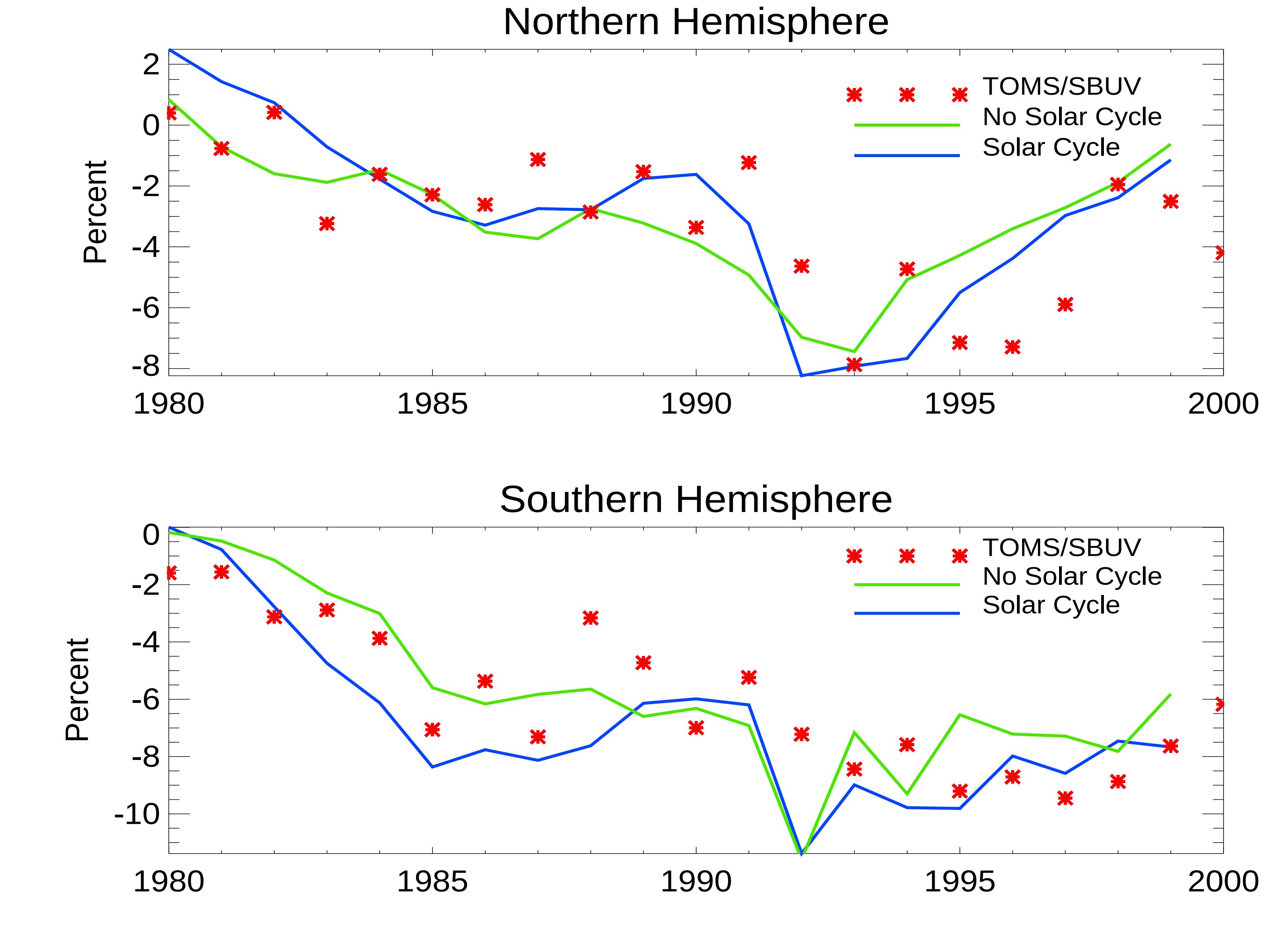
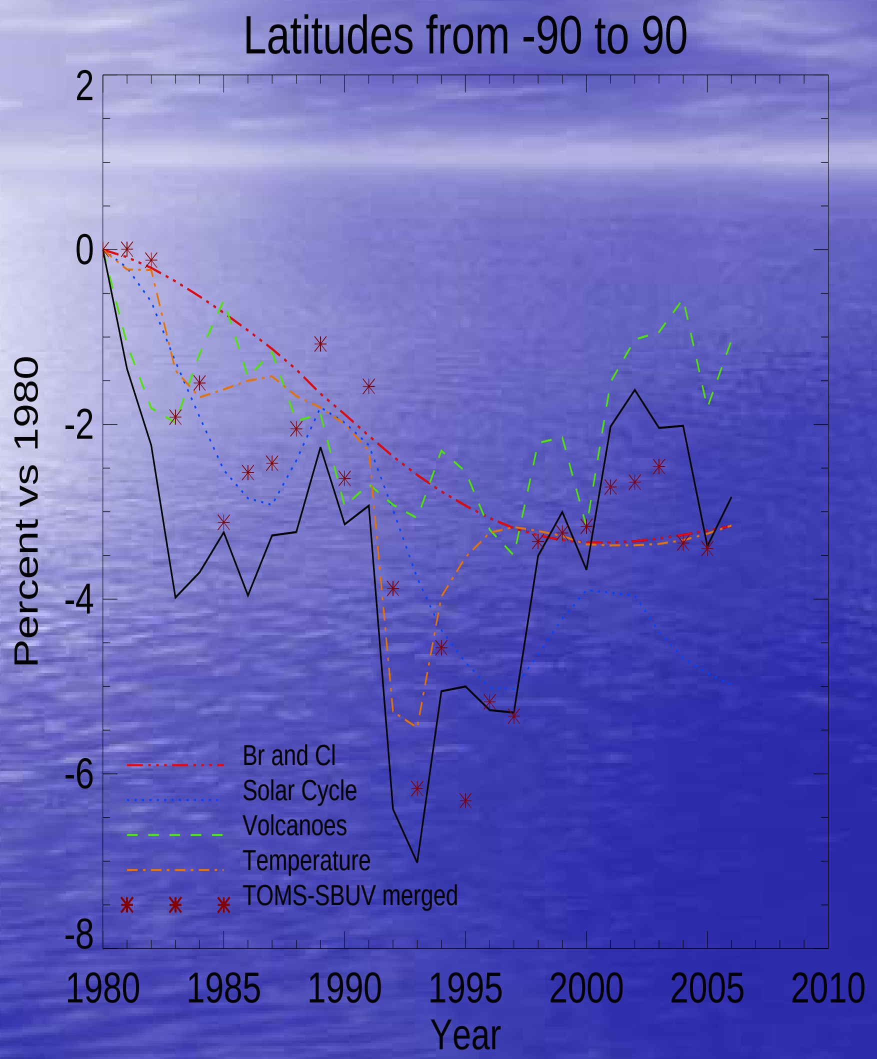
- RSHU-INM CCM was run for 1979-2003
- Source gases were varied according to WMO scenario [2006]
- SAD loading was estimated based on SAMS and SAGE data
- SST inter-year variations based on AMIP scenario
- Solar variability was included based on the sunspot data archive and solar UV radiation variability (Zerefos [1997], Lean [2000], Rottman [2000])

Column Ozone Changes relative its average for 1980-2000

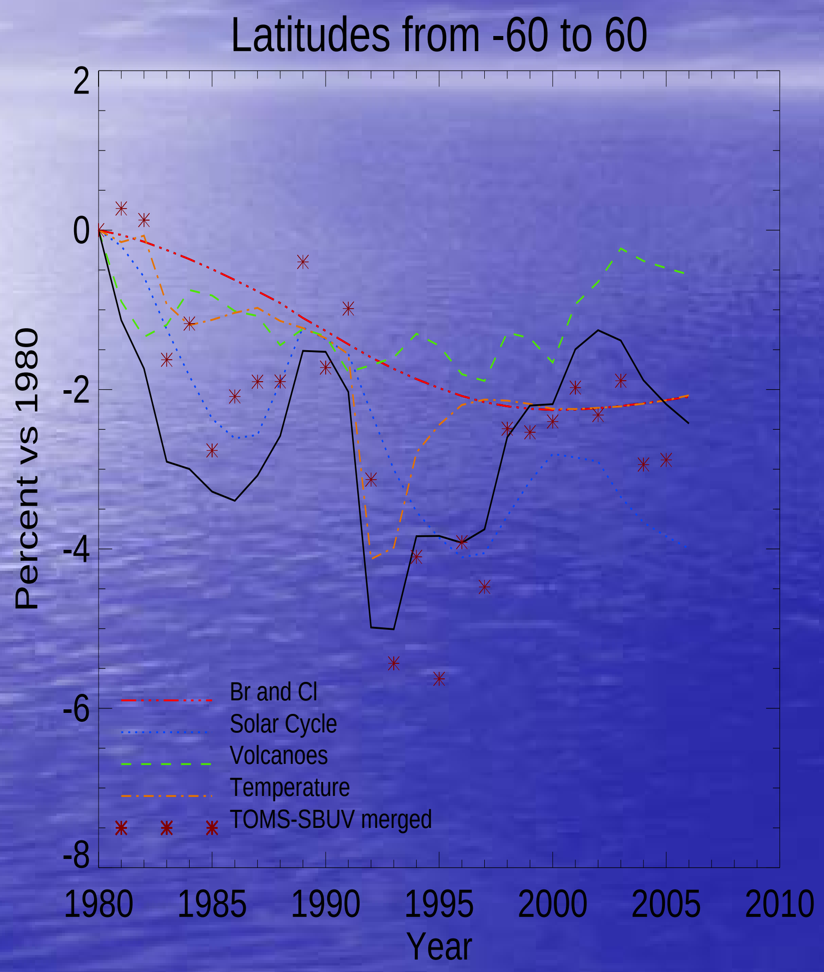


Global Ozone



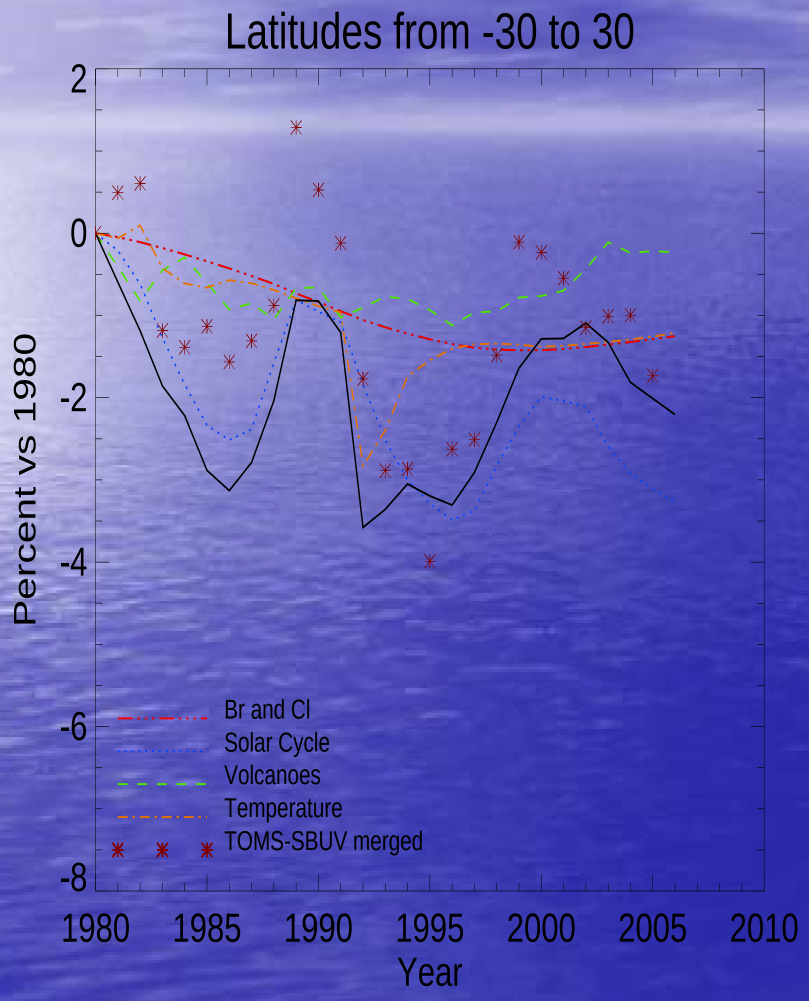
- Ozone depletion due to CFCs is up to 3%
- Man-made impact was stabilized by the end of 90th
- Ozone recovery started at mid 90th is mainly due to natural reasons (Solar Activity, Stratospheric Cooling, and Aerosol Cleaning)

Extra-polar Ozone



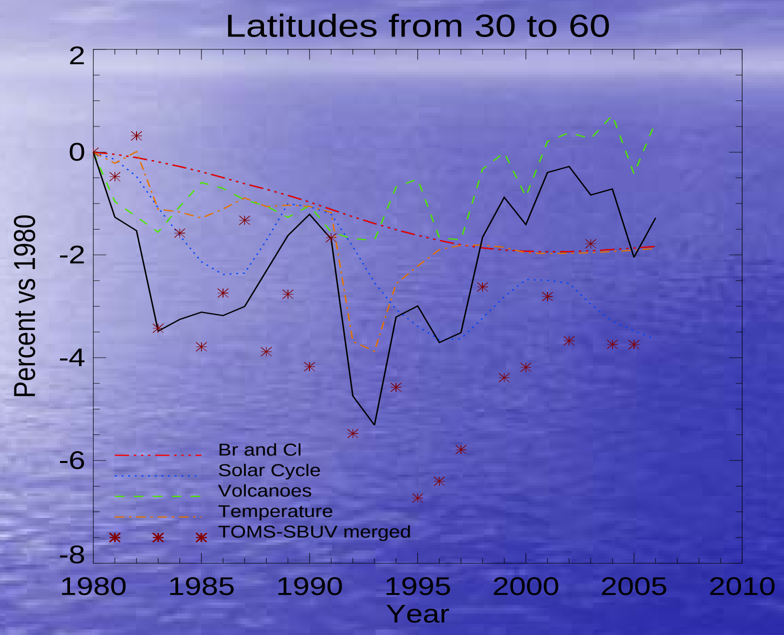
- Man-made effect up to 2% of ozone depletion
- Maximum ozone reduction in mid 90s (up to 6%) is due to Volcanoes Eruptions (Pinatubo 1991), solar activity minimum, delayed temperature impact

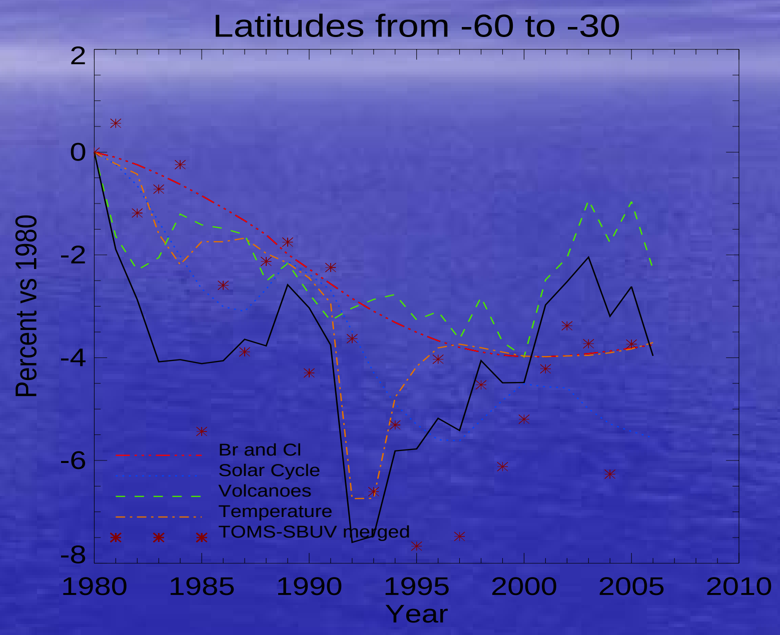
Tropical Ozone



- The role of anthropogenic factor is negligible (within 1%)
- 11-year Solar Cycle almost fully derive observed column ozone variability

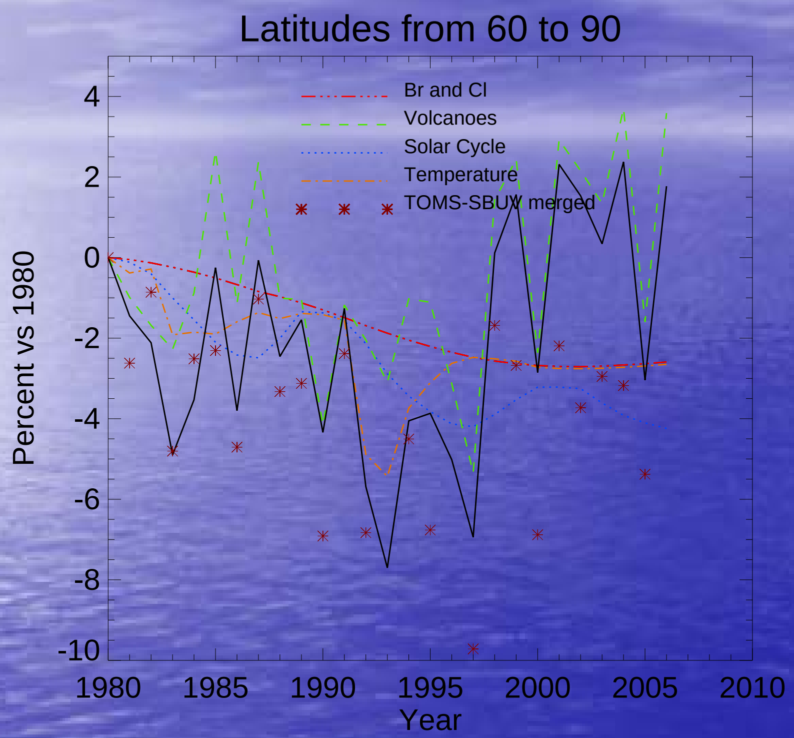
Inter Hemispheric Differences

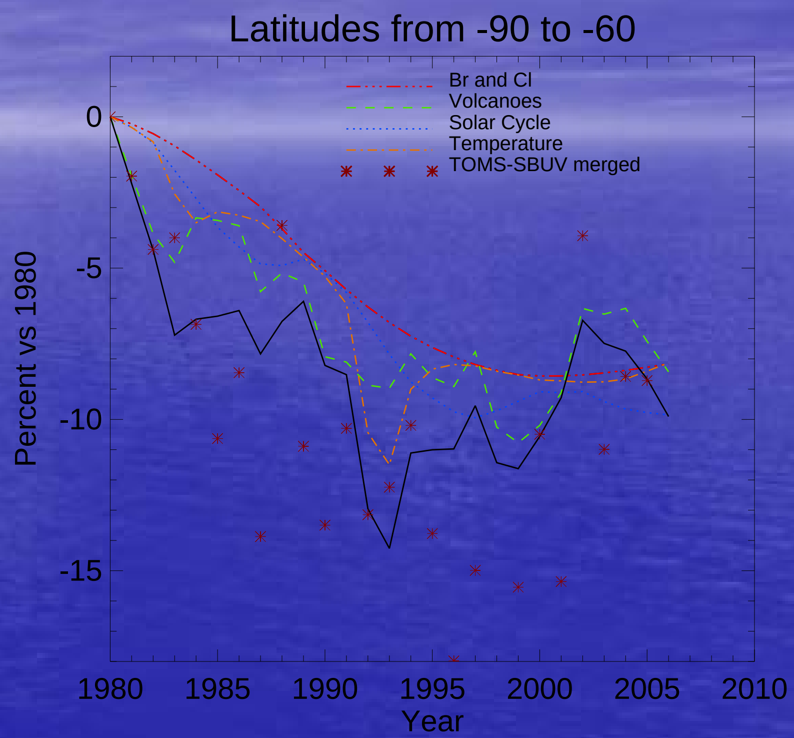




- Man-made effect differ up to two times
- Teмperature impact is postponed for Southern Hemisphere
- The role of dynamics – mass exchange with polar regions

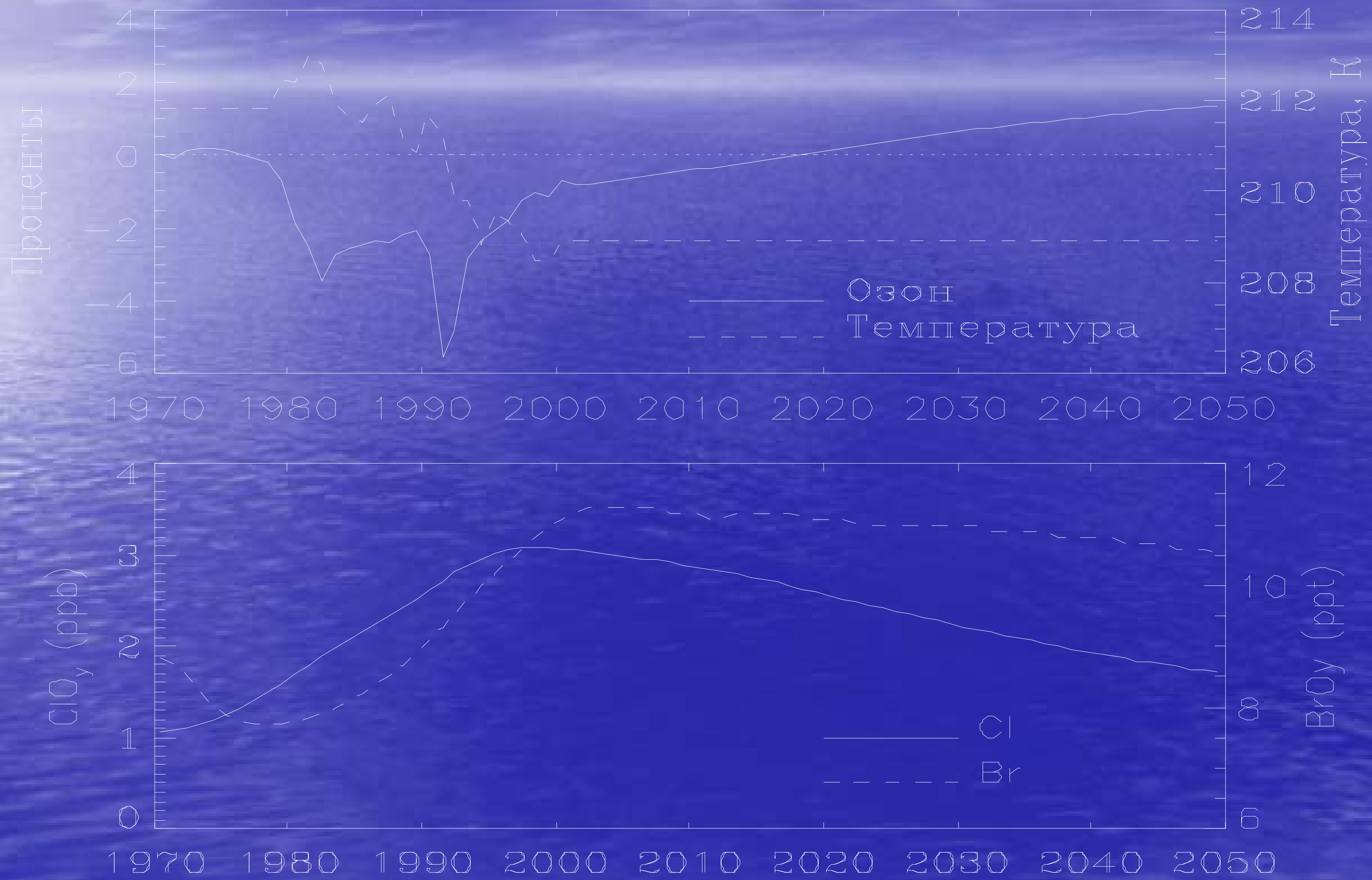
Polar Regions



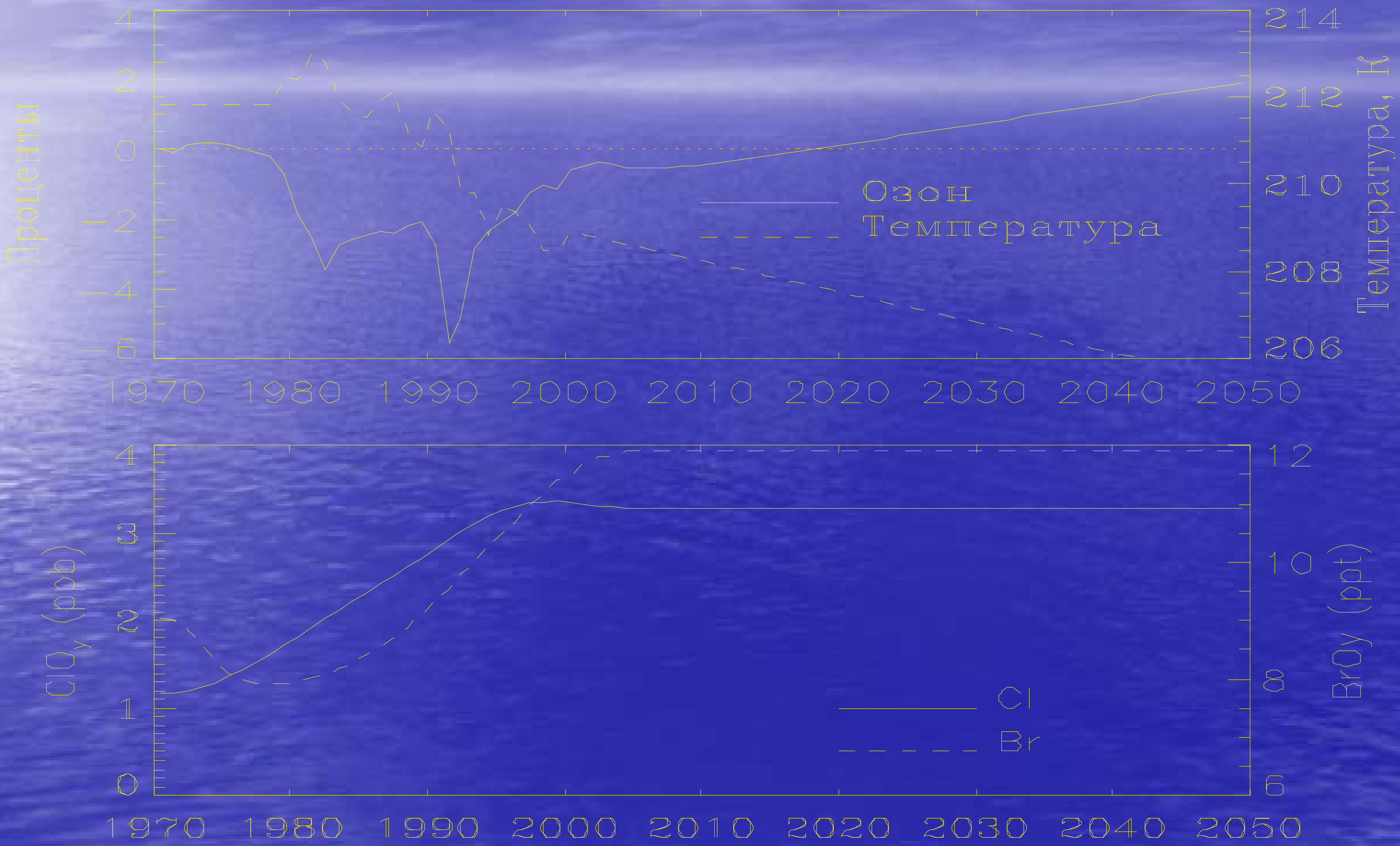


- Significant differences between Arctic и Antarctic
- Differences in anthropogenic effect up to 3-4 times
- Temperature variability is more important in Arctic

Prognostic ozone variability under Montreal Protocol Conditions



Prognostic ozone variability assuming continous cooling



Conclusions

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- The coupled interactive three-dimensional Chemistry Climate Model of lower and middle atmosphere has been developed
- Numerical experiments with CCM were carried out to study interactions between chemical and physical processes in the atmosphere
- Performed research has shown the importance of feedbacks between the chemical and physical processes which have both quantitative and qualitative impacts on the atmospheric climate