Total Column Ozone Winter and Spring Anomalies over the Territory of North Eurasia: Measurements and Numerical Modeling

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SPbU and RSHU Collaboration

Department of Atmospheric Sciences SPbU:

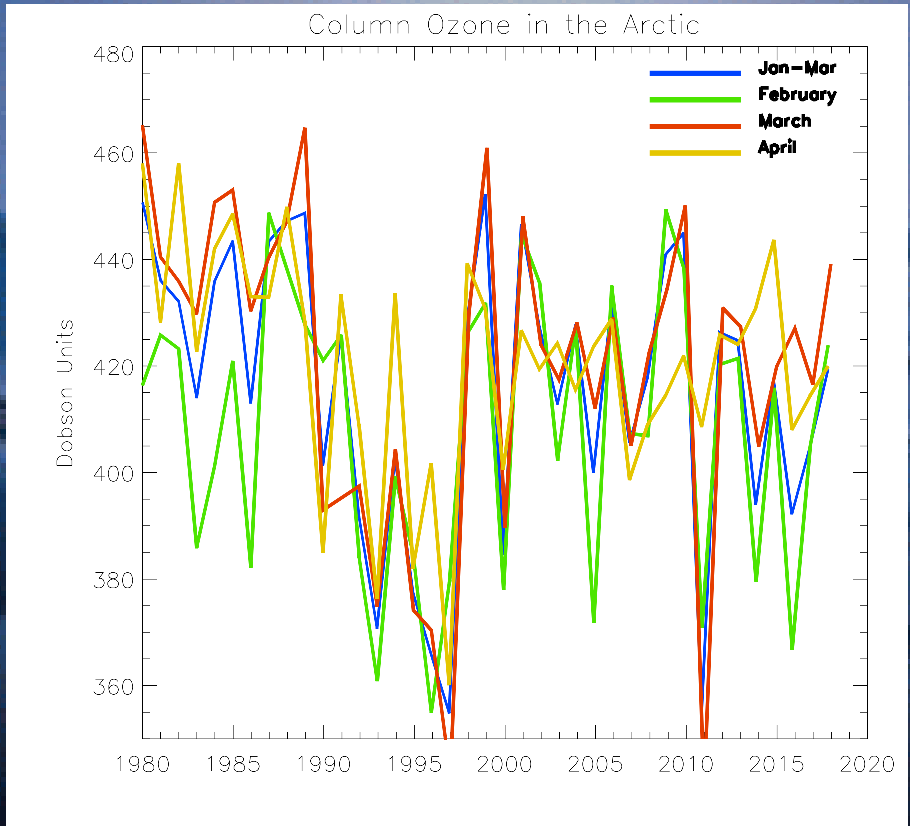
- Atmospheric gases and aerosol measurements and data analysis
- Ground based and satellite measurements using own instruments and retrieval algorithms

Russian State Hydrometeorological University:

- Numerical Modeling
- Global and Regional Chemistry-Climate and Chemistry-Transport Models applications for atmospheric composition case studies

Common SPBU and RSHU model and measurements comparison and analysis

Arctic Winter-Spring Column Ozone



- Mean values for the whole Arctic region north to 60 degrees
- The lowest TOC values were observed in 1997 and 2011 (and 2020)
- For years with low average ozone, the lowest values are in March
- On average in the Arctic in 2016 the ozone content was quite high

- **Solar Backscattered Ultra Violet (SBUV) Instrument**

Ground-based FTIR measurements

Instrumentation	Solar FTIR spectrometer Bruker 125HR
Spectral resolution	~0.005 cm^{-1} (unapodised spectra)
Location	Saint Petersburg – Peterhof (59.88 N, 29.82 E)
Time series	2009-2018
Retrieved gases (25 species)	H_2O, $H_2{}^{18}O$, HDO, CH_4, N_2O, CO, CO_2, C_2H_6, HCN, H_2CO, OCS, NH_3, CFC-11, CFC-12, HCFC-22, O_3, $^{16}O^{16}O^{18}O$ $^{16}O^{18}O^{16}O$, HCl, HF, HNO_3, $ClONO_2$, NO_2, C_2H_2, HCOOH

Stratospheric gases retrieval errors

Gas	O_3	NO_2	$ClONO_2$	HNO_3	HF	HCl	CFC-11	CFC-12	HCFC-22
DOFS	4.1	1.2	1.1	2.8	2.6	2.5	1.3	1.7	1.1
Error, %	2–2.5	10–14	25–30	8–12	5–7	5–7	8–10	4–5	5–7

Solar Backscattered Ultra Violet (SBUV) Data

NOAA's polar orbiting satellites carrying the SBUV/2 instrument.

- Space satellites with the SBUV type equipment crossed the equator approximately 14 times a day at the same local mean solar time, i.e., in longitude, the aisle points were at an angular distance of ~ 26 ° from each other.
- Measurements with SBUV (SBUV / 2) instruments are performed near the local vertical within an angle of ± 11.3 °.
- The SBUV spatial resolution is 180 × 180 km², the SBUV / 2 resolution is 168 × 168 km².

The SBUV Overpass algorithm interpolates satellite measurements to values at the WOUDC World Ozonometric Network stations (World Ozone and Ultraviolet Radiation Data Centre)

Infrared Fourier Spectrometer - 2 (IKFS-2)

<table>
<tr><td>Acronym</td><td colspan="5">IKFS-2</td></tr>
<tr><td>Full name</td><td colspan="5">Infrared Fourier Spectrometer - 2</td></tr>
<tr><td>Purpose</td><td colspan="5">Temperature/humidity sounding, ozone profile and total-column green-house gases</td></tr>
<tr><td>Short description</td><td colspan="5">IR interferometer, 2670 channels [see detailed characteristics below]</td></tr>
<tr><td>Background</td><td colspan="5">New development</td></tr>
<tr><td>Scanning Technique</td><td colspan="5">Cross-track: 30 steps to cover a swath of 1000 km if contiguous, up to 2500 km with gaps</td></tr>
<tr><td>Resolution</td><td colspan="5">35 km at s,s,p.</td></tr>
<tr><td>Coverage / Cycle</td><td colspan="5">Near-global coverage twice/day (with gaps) or once/day (continuous)</td></tr>
<tr><td>Mass</td><td>50 kg</td><td>Power</td><td>50 W</td><td>Data Rate</td><td>600 kbps</td></tr>
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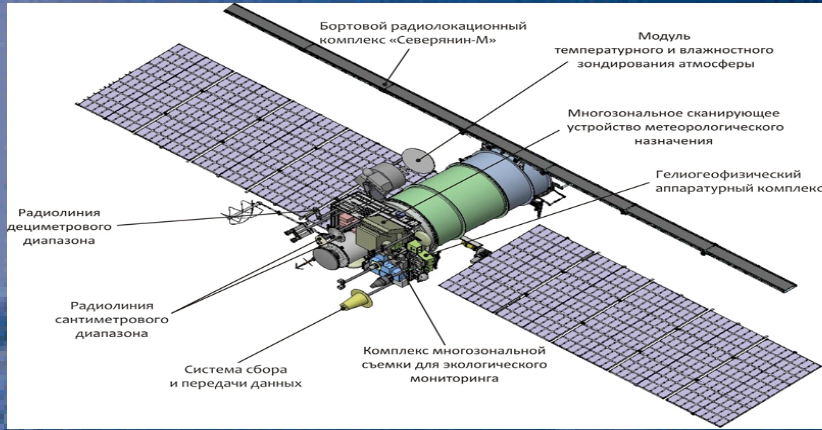
Providing Agency	Roscosmos
Instrument Maturity	Backed by strong heritage
Utilization Period:	2015-01-15 to ≥2027
Last update:	2014-05-26

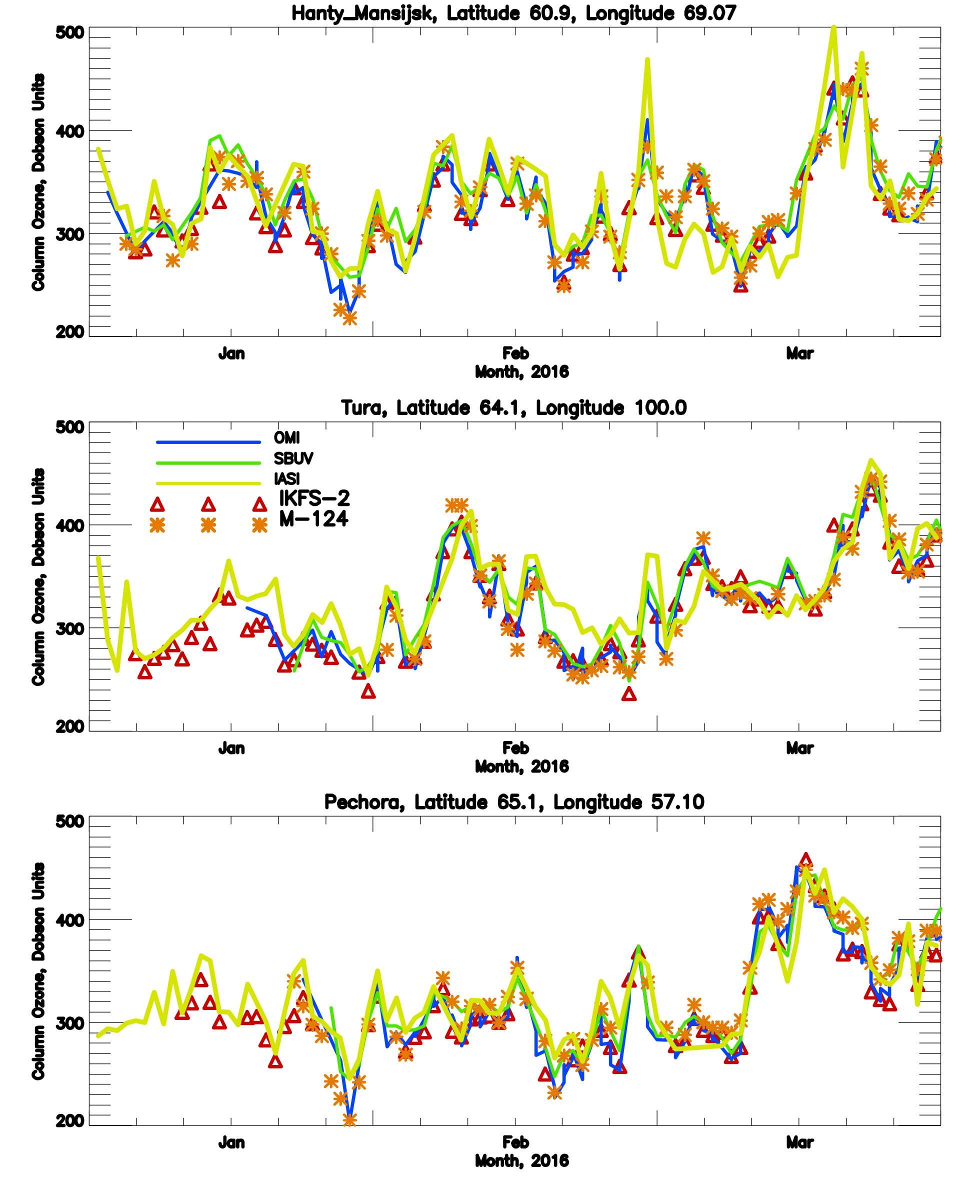


Meteor-3M (RosHydroMet)

- Meteor-M N2 (see instrument status) Jul 2014 - 2019
- Meteor-M N2-1 (see instrument status) 2017 - 2022
- Meteor-M N2-2 (see instrument status) 2017 - 2022
- Meteor-M N2-3 (see instrument status) 2020 - 2025
- Meteor-M N2-4 (see instrument status) 2021 - 2026
- Meteor-M N2-5 (see instrument status) 2022 - 2027

Spectral range (µm)	Spectral range (cm^{-1})	Spectral resolution (unapodised)	NEΔT @ specified scene temperature
5-15 µm	665-2000 cm^{-1}	0.5 cm^{-1}	0.5 K @ 280 K

Total Ozone Measurements provided by M-124, OMI, IKFS-2, IASI, and SBUV



According to regular extensive validation programs, total ozone measurement errors can be from 1–2% to 10 %, depending on the method, device, time, and place of the measurements.

Independent assessments of TOCs empirical measurement random errors showed values of 3–4.5% for IASI, 3.5–4.5% for IKFS-2, 2–3.5% for M-124, and 2–3% for OMI instruments.

2015/2016 Winter Ozone Anomalies over Eurasia

In the first quarter of 2016, three short-term periods with significantly lower daily total ozone columns (TOCs), compared to the climatologically averaged values for the period from 1979 to 2018, were observed over the territory of Russia. TOCs decreases reached:

•39–52% (on 26 January–1 February 2016 over the northern regions of the Urals and Siberia)

•30–50% (on 20 February–3 March 2016 over northern Siberia)

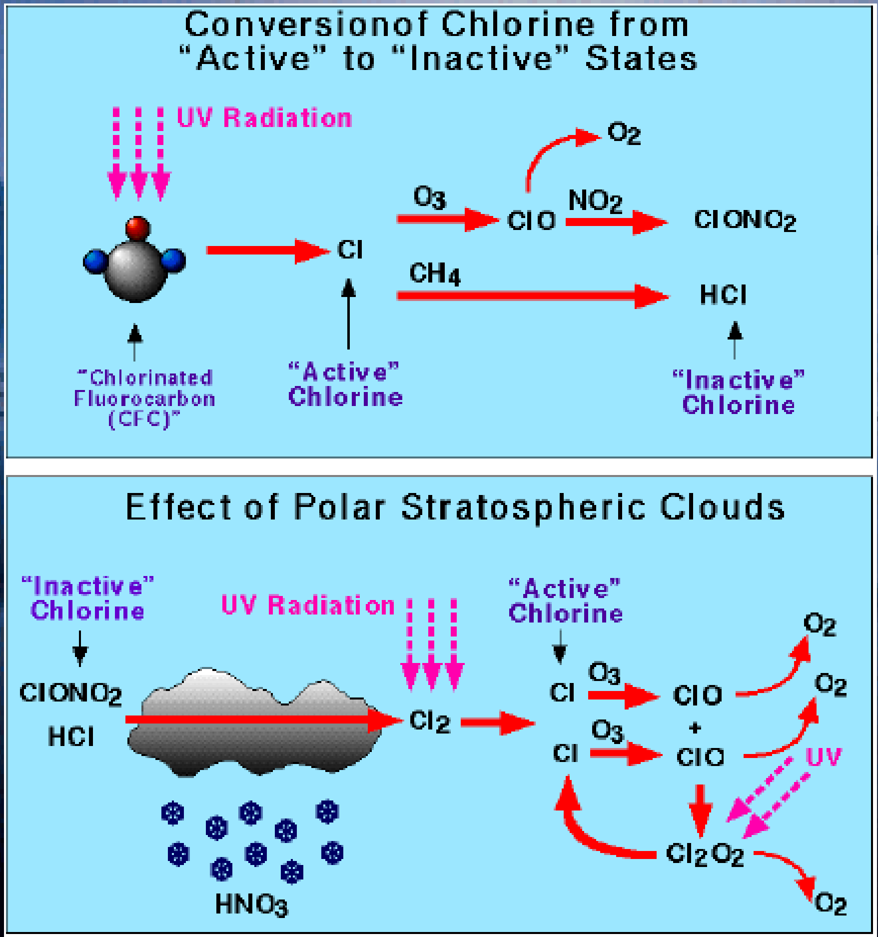
•27–39% (on 9–19 March 2016 over central Siberia)

of daily averaged values of ozone column (191–257, 227–321, and 257–321 DU for these three periods).

Objectives

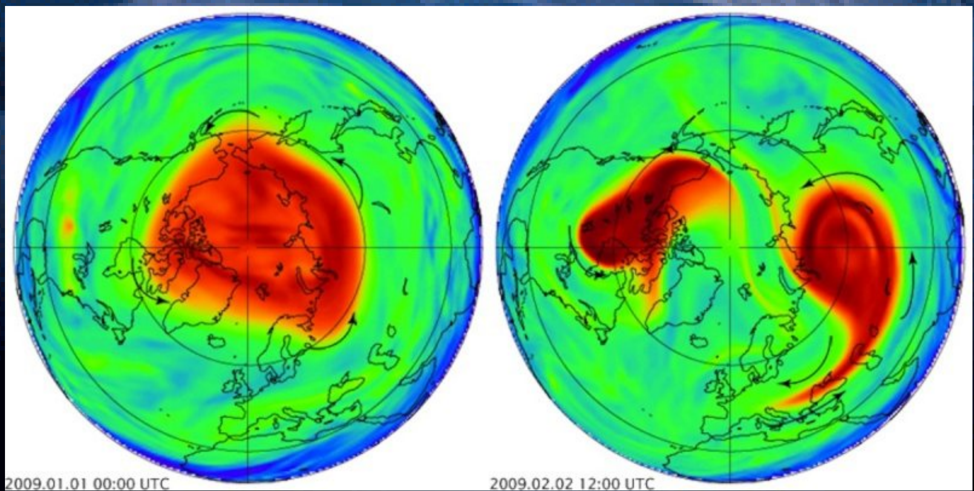
- Based on the analysis of remote satellite and ground-based measurements of ozone content, as well as the results of numerical modeling, assess the significance of photochemical and dynamic factors in the formation of ozone anomalies in the Arctic and Subarctic in the winter of 2015-2016.
- Compare to other winter/spring with low column ozone registered (1996/1997, 2010/2011, 2019/2020 in perspective)

Chemical Factor: Heterogeneous Activation on the PSC surface and Spring Ozone Destruction



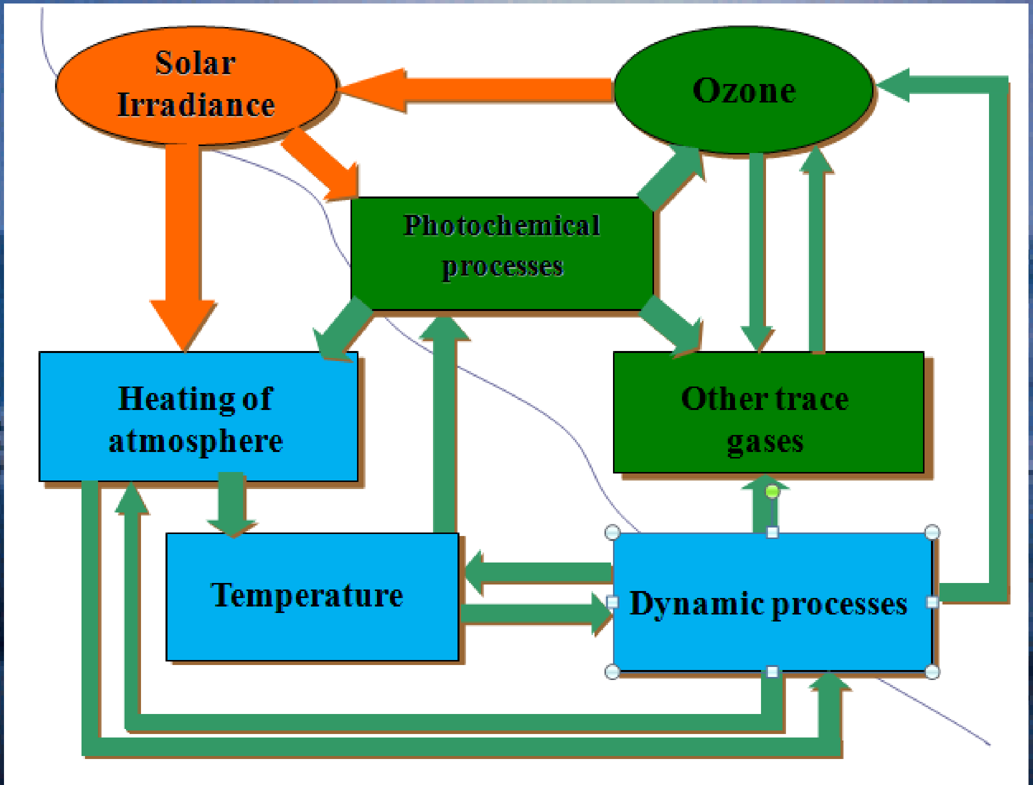
- Active chlorine (bromine) destroys ozone in halogen catalytic cycles
- Inactive chlorine (bromine) is neutralized by nitrogen and hydrogen compouns
- Denitrification and dehydration of the polar stratosphere allow chlorine (bromine) to be in active form for a long time and destroy ozone

Dynamical Factors: Planetary waves and polar vortex



- Large-scale quasi-stationary longitudinal perturbations of atmospheric parameters (stationary planetary waves) are forced oscillations of the atmosphere that are excited in the troposphere due to inhomogeneities of the orography and heating of the underlying surface
- Planetary waves propagating from the troposphere to the stratosphere interact with the mean flow and affect the stability of the circumpolar vortex
- As a result of sudden stratospheric warming (SSW), the circumpolar vortex can divide, shift and collapse.

Model of the Gas Composition of the Lower and Middle Atmosphere RSHU

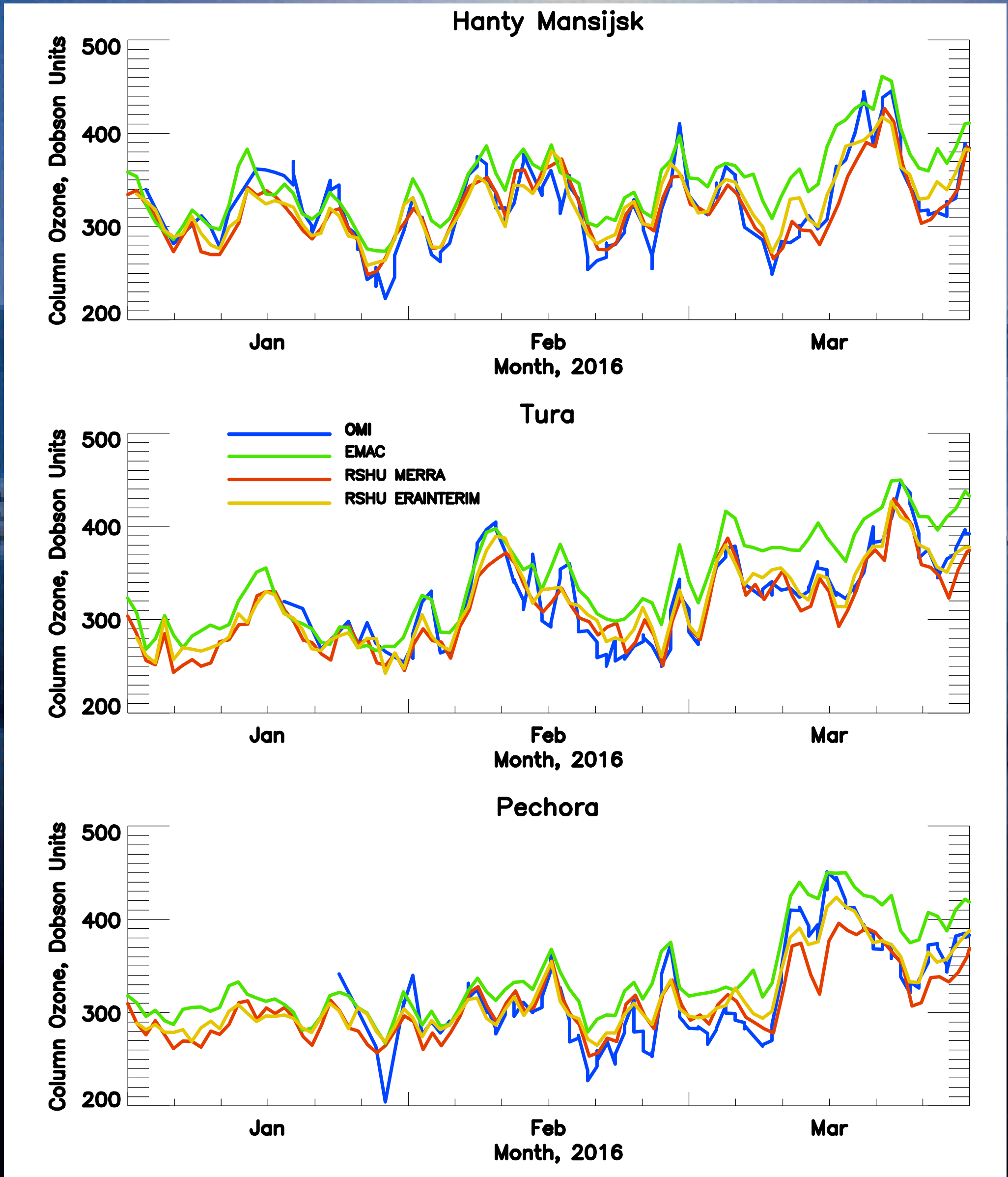


Chemistry-Climate Model (CCM) -> Chemistry-Transport Model (CTM)

- Global finite-difference with off-line data from re-analysis of temperature, wind speed, humidity and pressure
- The variability of oxygen, nitrogen, chlorine, bromine, hydrogen and carbon gases is considered;
- The variability of surface concentrations or fluxes from the surface is given for gases that affect the content of stratospheric components;
- Model of formation and evolution of sulphate aerosol and polar stratospheric clouds;
- Heterogeneous reactions on the surface of sulphate aerosol and polar stratospheric clouds are considered;
- The processes of gravitational sedimentation of aerosol particles, as well as the exchange of gases between the stratosphere and troposphere

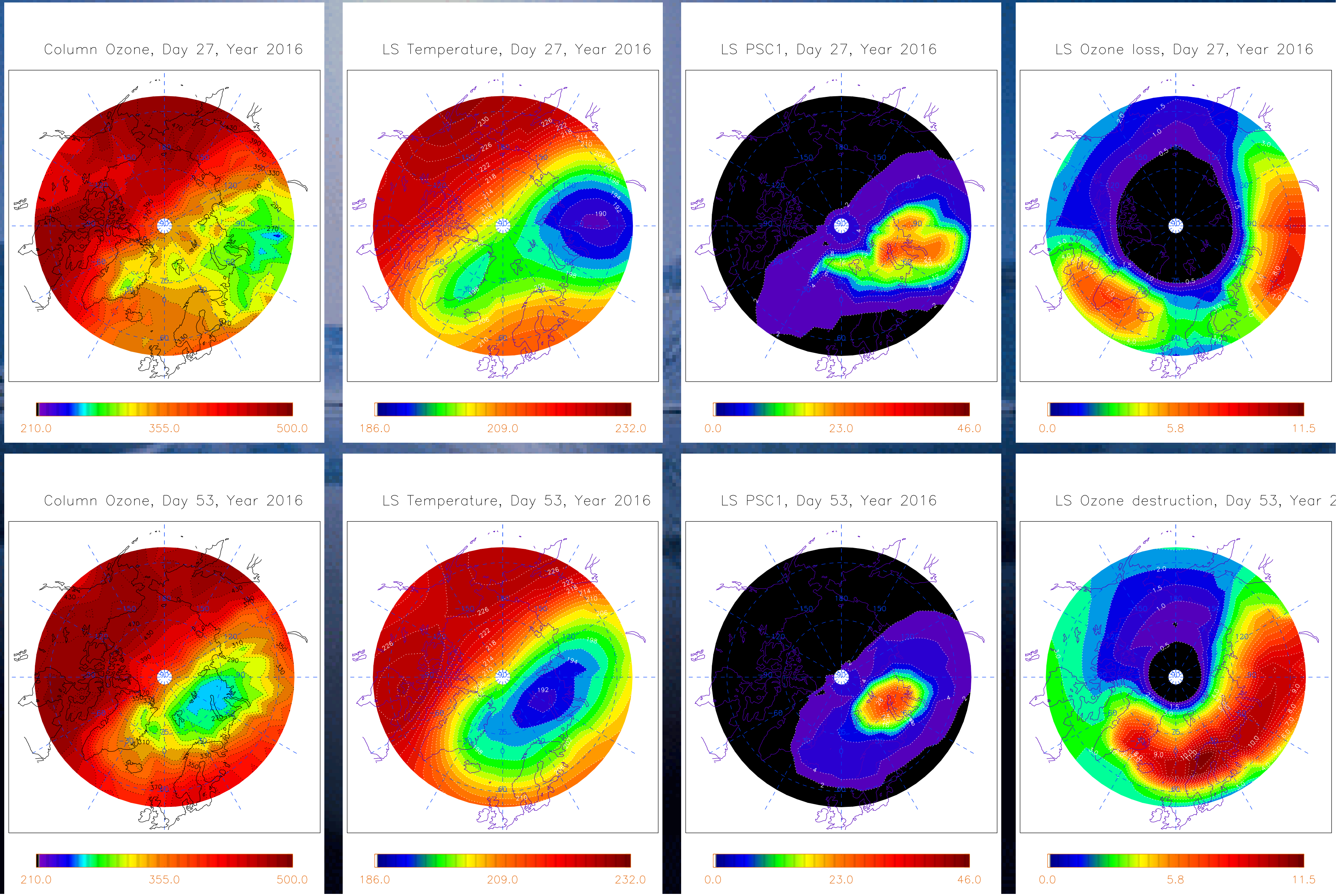
The option of using re-analysis data MERRA, MERRA-2, JRA, ERA-INTERIM

Total Ozone Measurements provided by OMI and Model Simulation Results from EMAC and RSHU



- Both models sufficiently describe time variations of the total ozone content
- On certain days, the differences between measurements and modelling can be up to 20–30%.
- The both models often overestimate the total ozone content measured by the OMI instrument
- Comparison of the results of the both RSHU CTM simulation, using different re-analysis data sets, show that for MERRA data, the column ozone is systematically lower than for ERA-Interim data

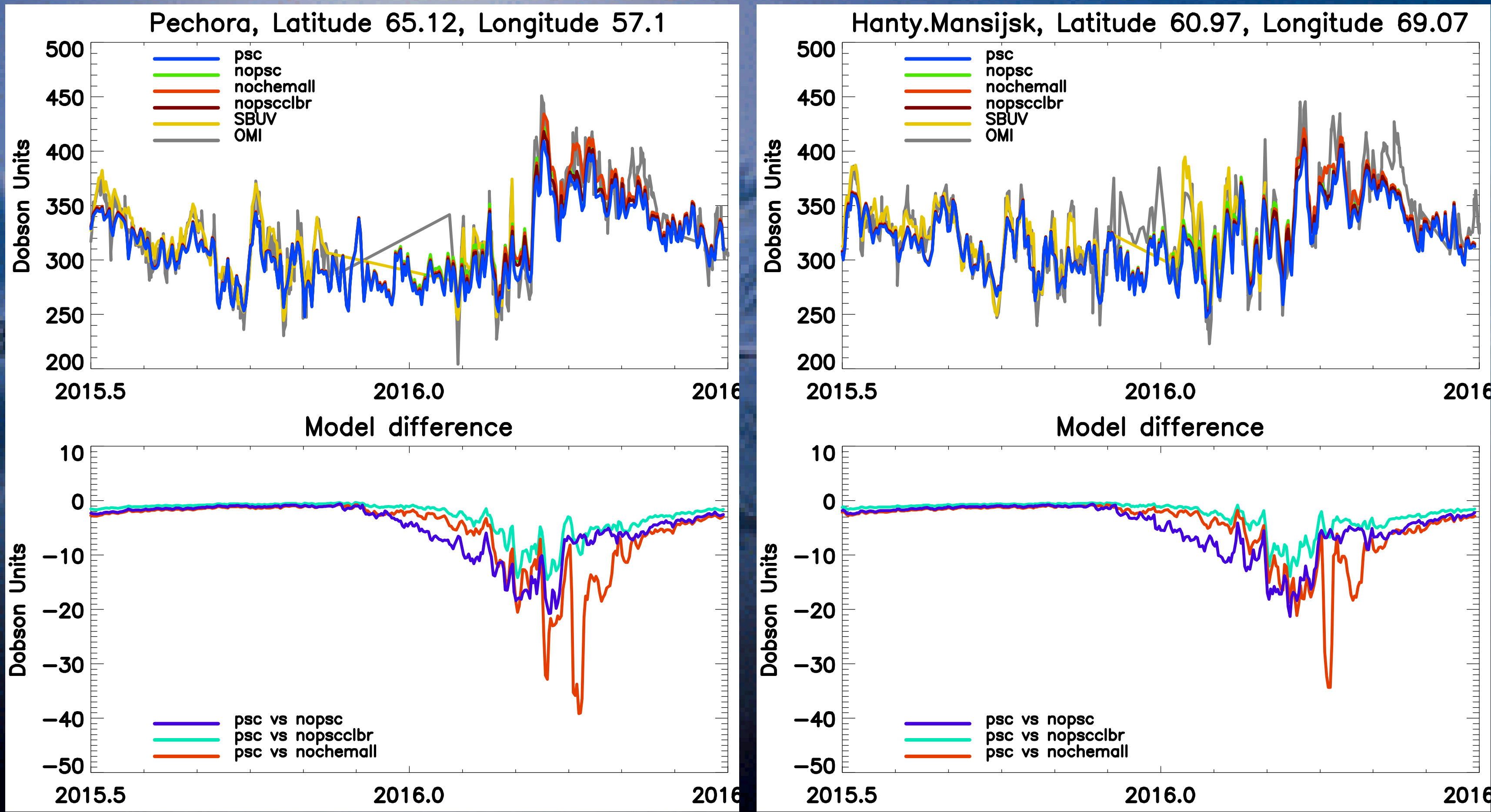
Lower Stratosphere Parameters for the Days of Minimum Column Ozone



Analysis of the Processes that Define Observed Ozone Variability

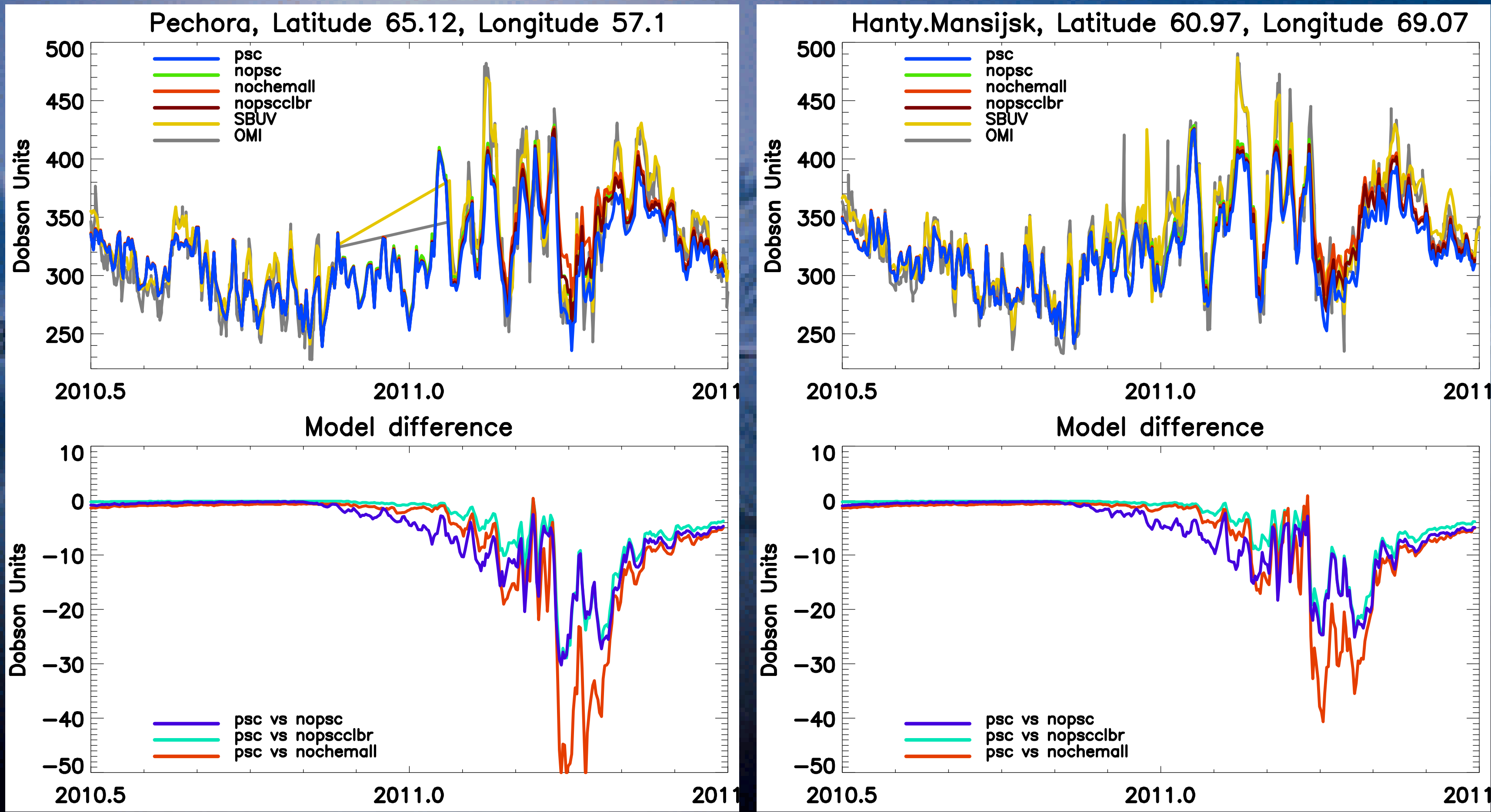
- Two days with the lowermost column ozone registered at all stations were chosen for extended analysis. These days are: January 27, 2016 (day 27) and February 21, 2016 (day 53)
- The low value column ozone regions are consistent with the low stratospheric temperature. This may be a result of dynamical isolation, which leads to stratospheric cooling and ozone deficit due to lack of mass and heat exchange with neighbor regions or ozone depletion may be caused by local destruction initiated by the polar stratospheric clouds formation under low temperature conditions.
- Enhanced PSCs surface area is located at the same regions where low stratospheric temperatures were registered. This is obvious consequence of stratospheric cooling and may lead to heterogeneous chlorine and bromine activation followed by ozone depletion similar to the Antarctic ozone hole formation
- Location of zones with enhanced ozone destruction is closed to the regions with estimated low column ozone, but is not fully consistent.
- Minimum local photochemical ozone lifetime, estimated as reciprocal of ozone destruction coefficient, is about 200 days.

2015-2016 Winter Column Ozone for Scenario with and without modeled PSCs, Polar Chemistry and Cl and Br Cycles



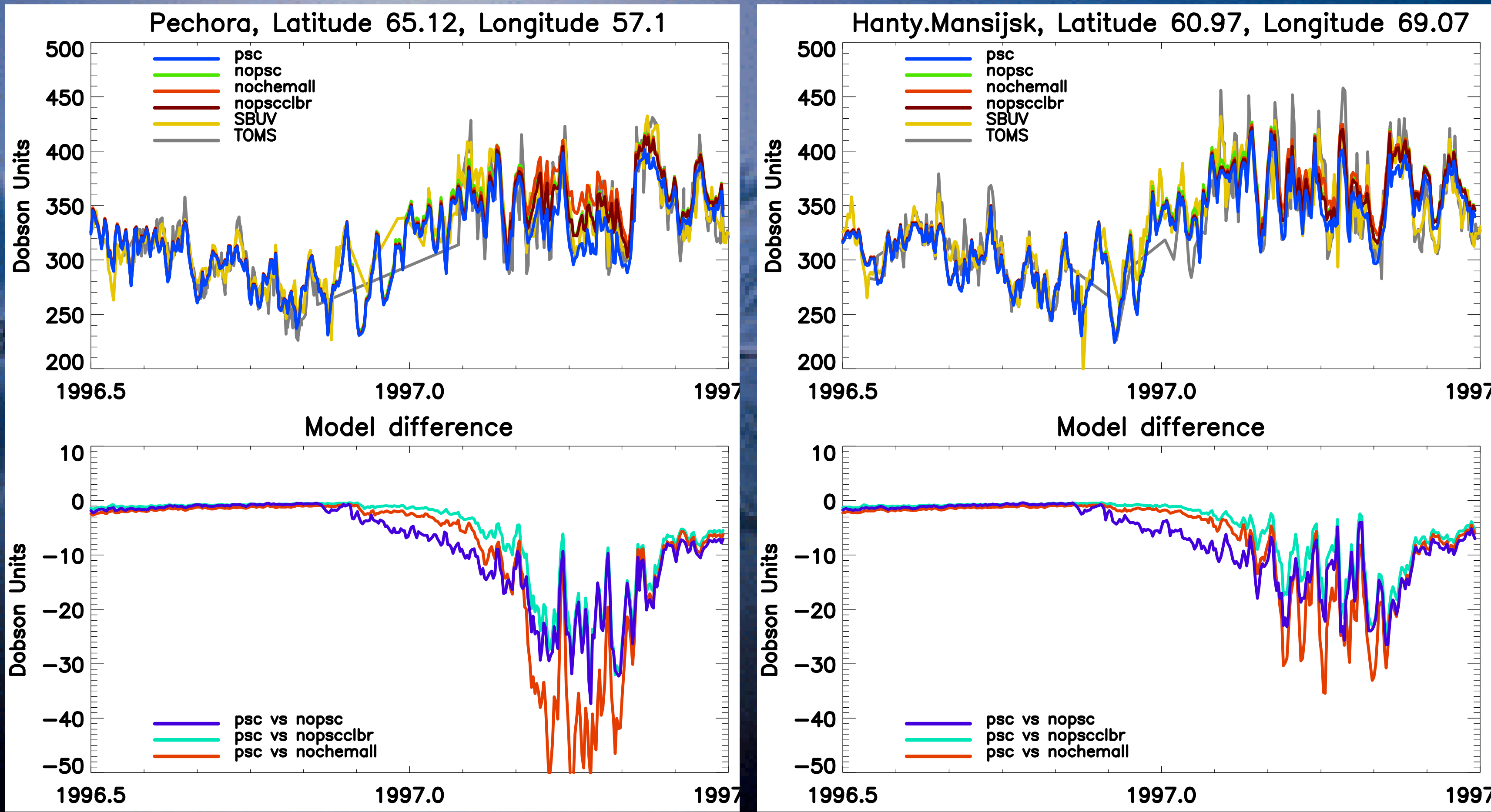
- Sudden Stratospheric Warming in March 2016 "uplifted" starting point for spring ozone depletion

2010-2011 Winter Column Ozone for Scenario with and without modeled PSCs, Polar Chemistry and Cl and Br Cycles



There is significant ozone reduction even without any chemical destruction!!!

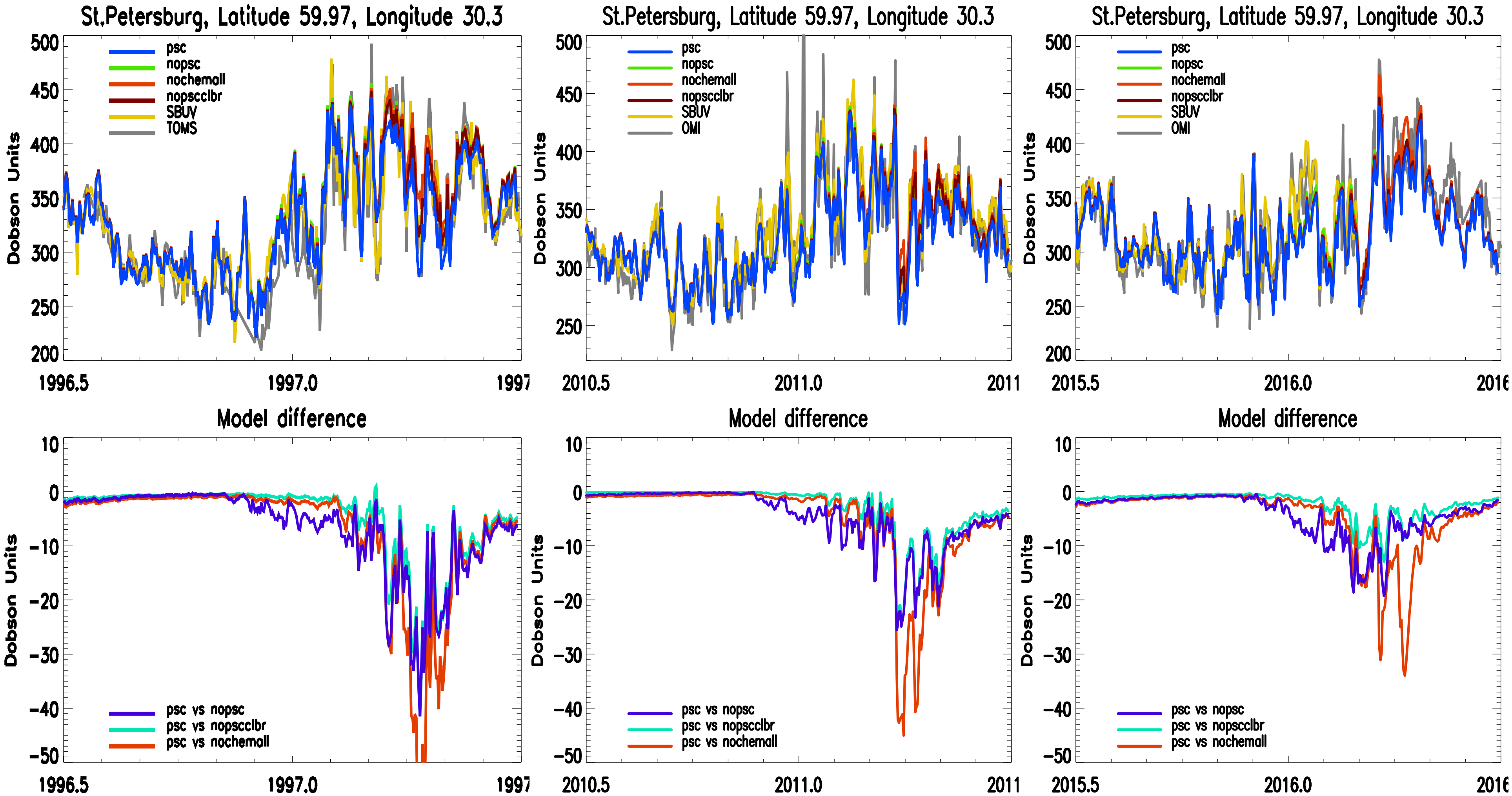
1996-1997 Winter Column Ozone for Scenario with and without modeled PSCs, Polar Chemistry and Cl and Br Cycles



There is significant ozone reduction even without any chemical destruction!!!

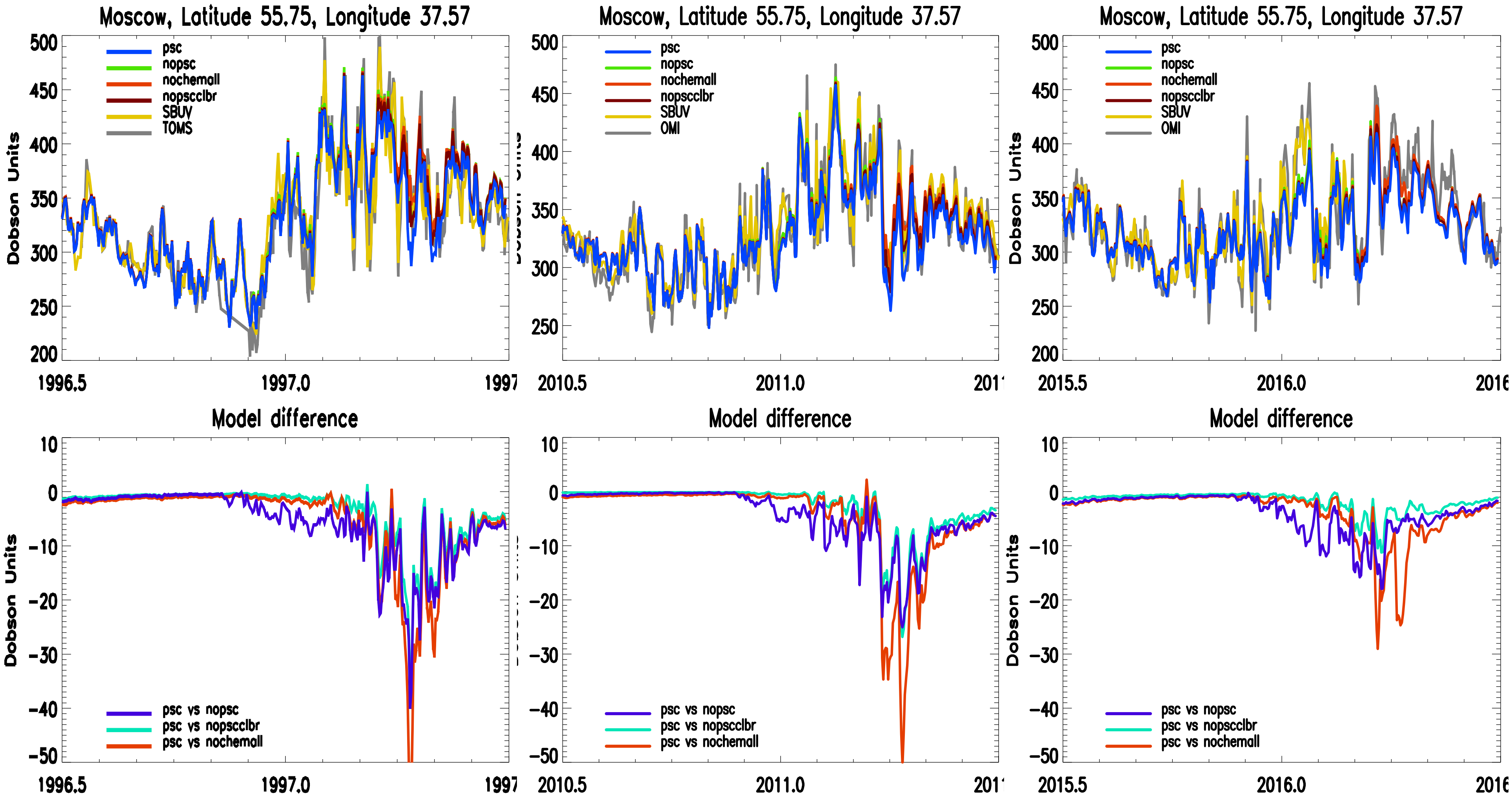
Evaluation of the Influence of Polar Processes in St. Petersburg

The difference between the scenarios with and without polar heterogeneous chemistry



Evaluation of the Influence of Polar Processes in Moscow

The difference between the scenarios with and without polar heterogeneous chemistry



Conclusions

- Ozone anomalies were observed over the territory of the Urals and Siberia in winter and the beginning of spring 2016.
- Current monitoring systems (including the new Russian Infrared Fourier Spectrometer IKFS-2) and modern 3-dimensional atmospheric models provide a good representation of the occurrence of the observed TOC anomalies
- Analysis of the role of chemical and dynamical processes in the observed ozone variability over the Russian Federation was based on the RSHU CTM calculations.
- This analysis demonstrated that it is unlikely that local photochemical ozone destruction, initiated by heterogeneous halogen activation on the particles of PSCs that formed under the observed low temperatures, is responsible for the short-term local minimum ozone values.
- The prevalent reason for the observed low TOCs may be dynamical flux divergence out of regions with observed low ozone content ;
- The similar analysis for unprecedented low ozone during 2019/2020 Winter/Spring over North Eurasia is on the way


Thanks for Your Attention!!!