BELARUSIAN STATE UNIVERSITY

NATIONAL OZONE MONITORING
RESESARCH & EDUCATION CENTRE
(**NOMREC**)

Modelling local ozone anomalies with OpenIFS

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OpenIFS User Meeting 2017 ***ICTP, Trieste***

The Abdus Salam
International Centre
for Theoretical Physics

Introduction - NOMREC BSU

NATIONAL OZONE MONITORING RESEARCH AND EDUCATION CENTRE (**NOMREC**)

- Founded 1997 as an Institution of the Belarusian State University

- Primary areas of research include different aspects of atmospheric physics related to atmospheric ozone:

  - Development of scientific instruments for measurements of stratospheric ozone, surface ozone and other trace gases in the atmosphere (e.g., NO_2)
  - Monitoring of atmospheric composition in Belarus and Antarctica

  - *Statistical analysis* of observational and reanalysis data aimed at studying interconnections between ozone and weather and climate parameters

- **Numerical modelling** of atmospheric processes in the troposphere and the stratosphere:
  - NWP development in Belarus (in coop. with Republican Centre for Hydrometeorology and BSU Faculties), NWP teaching
  - **Stratosphere-troposphere interactions** research
  - **Ozone**-climate connections research

Analysis

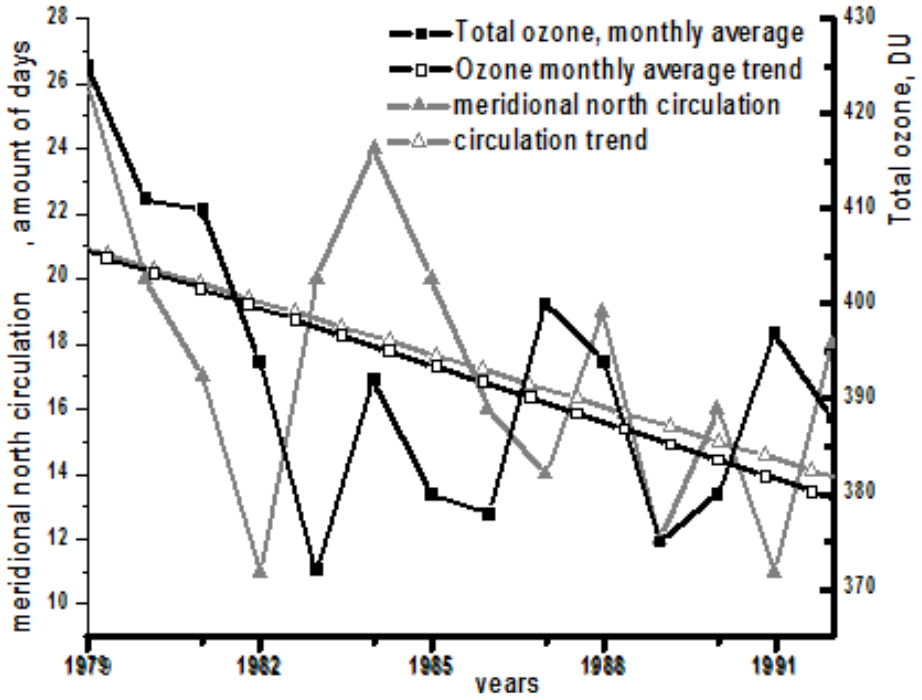
Statistical analysis of observational and reanalysis data:

- Climatic trends in the stratospheric ozone layer:
  - a shift of the ozone annual course maximum over the territory of Belarus for earlier terms is revealed. In 80’s the maximum monthly average values were observed in April, but since the middle 90’s the annual maximum has been shifted to March
- Coupling of ozone with atmospheric general circulation:
  - repeatability and fluctuations of macroscale circular processes over the European sector of the Northern hemisphere (classification of circular processes and calendars of circulating epochs according to B.L. Dzerdzeevsky) - through the Aprils, 1979-1997, a number of days with a meridional northern circulation showed a significant negative trend, whereas increase of a meridional northern circulation is observed in March

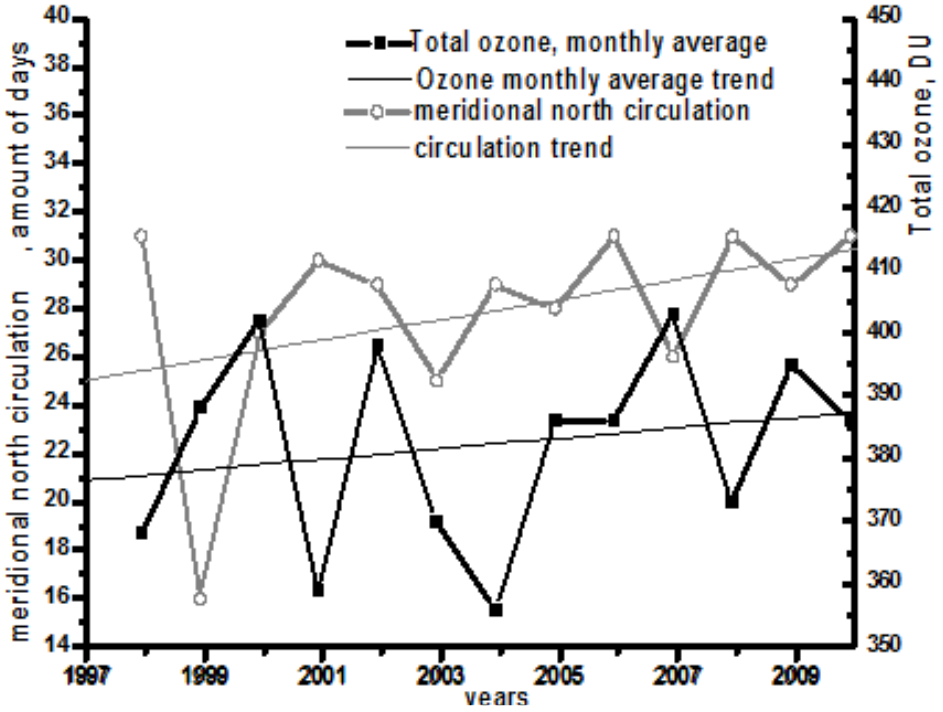
Introduction - NOMREC BSU

Statistical analysis of observational and reanalysis data:

- comparison of number of days with a certain type of circulation to monthly average TO values of the same periods shows that shift in the annual ozone maximum to earlier dates is connected with fluctuations of macroscale circular processes in the Northern hemisphere



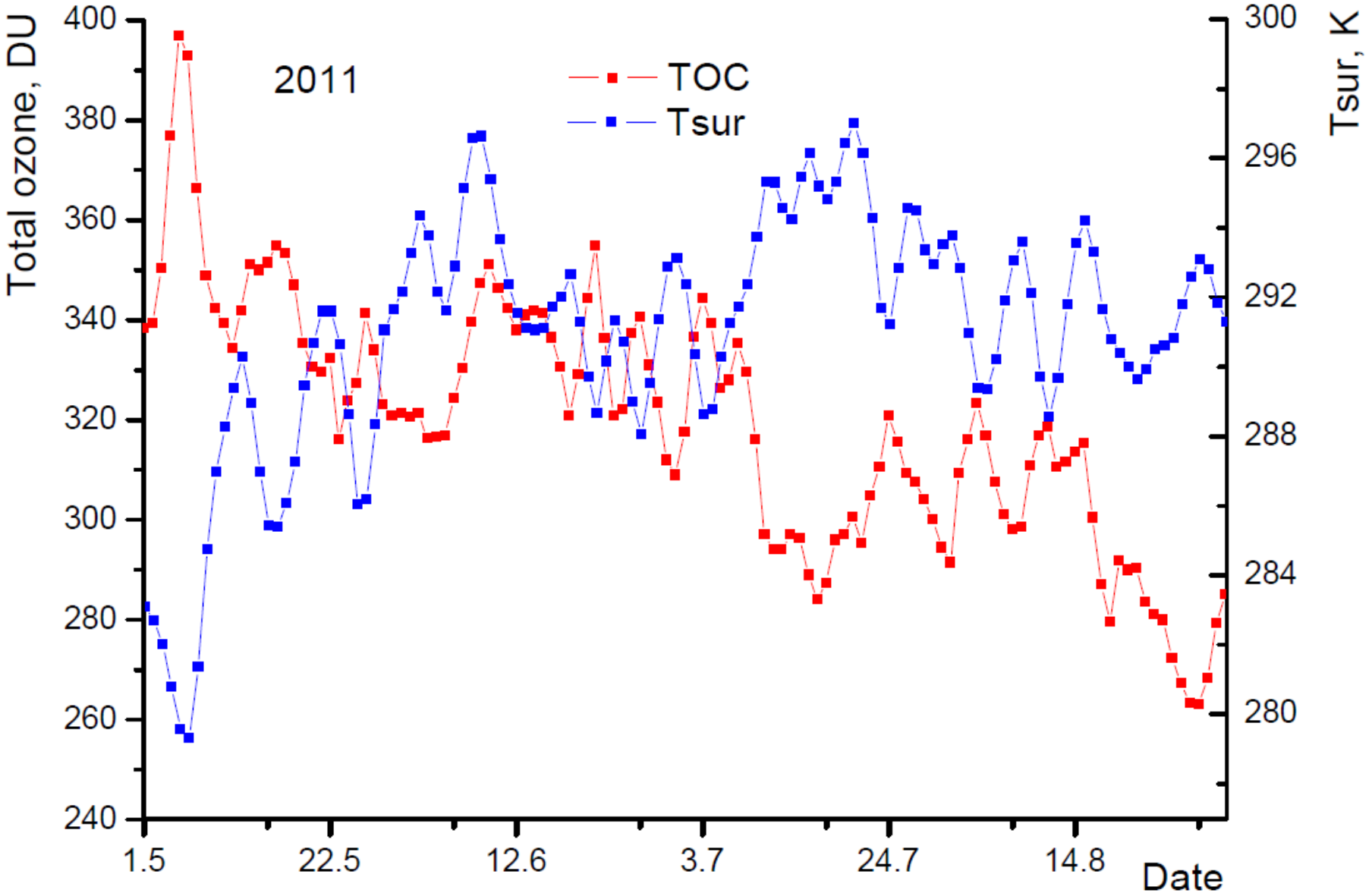
Trends of the TO monthly average values and the number of days with a meridional northern circulation for April, 1979-1992.



Trends of the TO monthly average values and the number of days with a meridional northern circulation for March, 1997-2009

Analysis

Statistical interconnection between stratospheric ozone and tropospheric (surface) parameters: Total ozone column vs. Surface temperature

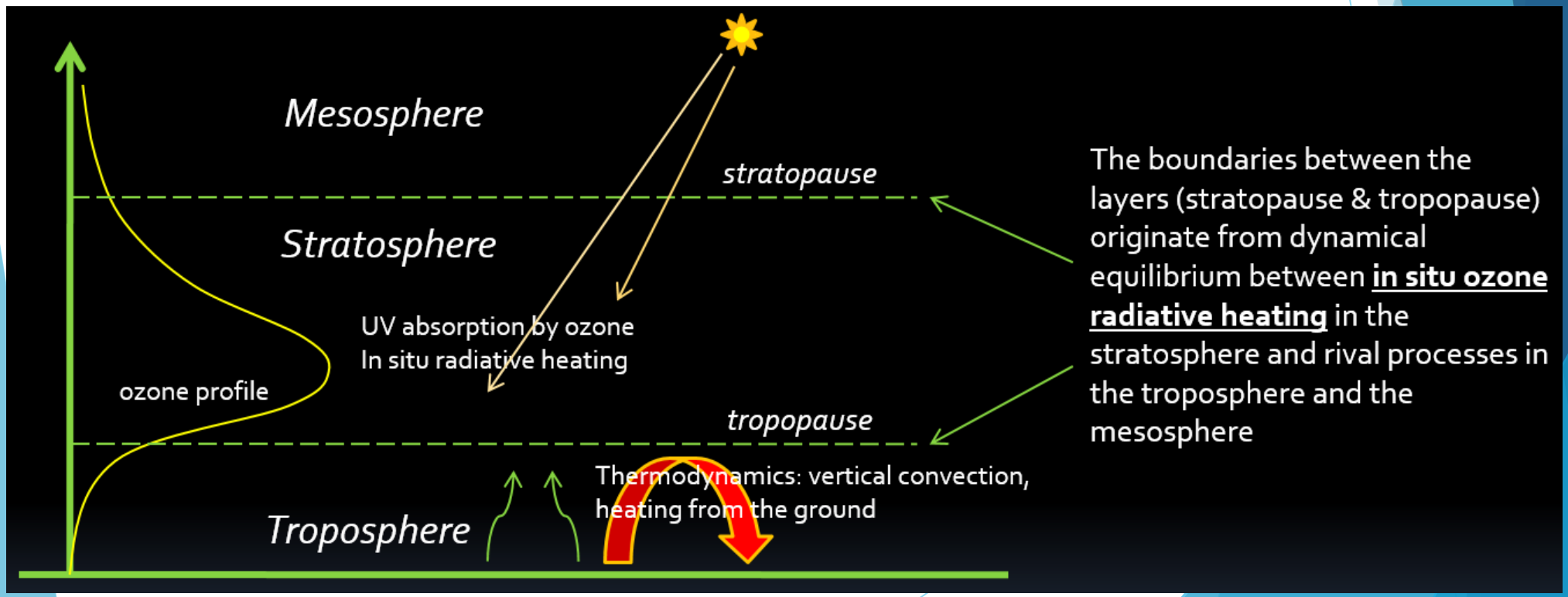


Ozone and Circulation:

Absorption of solar radiation by ozone is responsible for determining thermal structure of as much as 40 km atmospheric layer (three fundamental surfaces: Tropopause, Stratonull, Stratopause)

Tropopause height - a result of two rival categories of processes:
- *Deep vertical convection in the troposphere* *and the*
- *Radiative heating of the stratosphere (from the ozone cycle)*

stratosphere-troposphere interactions



Ozone and Circulation

Sources of variability in stratosphere / mesosphere / thermosphere:

- Solar activity:
  - Direct flux of radiation and energetic particles
  - Particles from Earth's magnetosphere

E.g.: solar proton events

- Changes in spatial distribution of ozone (O_3) and other active gases (CO_2, H_2O, CH_4, NO_2, …)

- Dynamical variability:
  - ***Sudden stratospheric warmings*** !
  - Gravitational waves, Rossby waves, …
  - Tidal phenomena
  - … … …

- **Tropospheric weather phenomena – interaction in the tropopause region**

Thermosphere

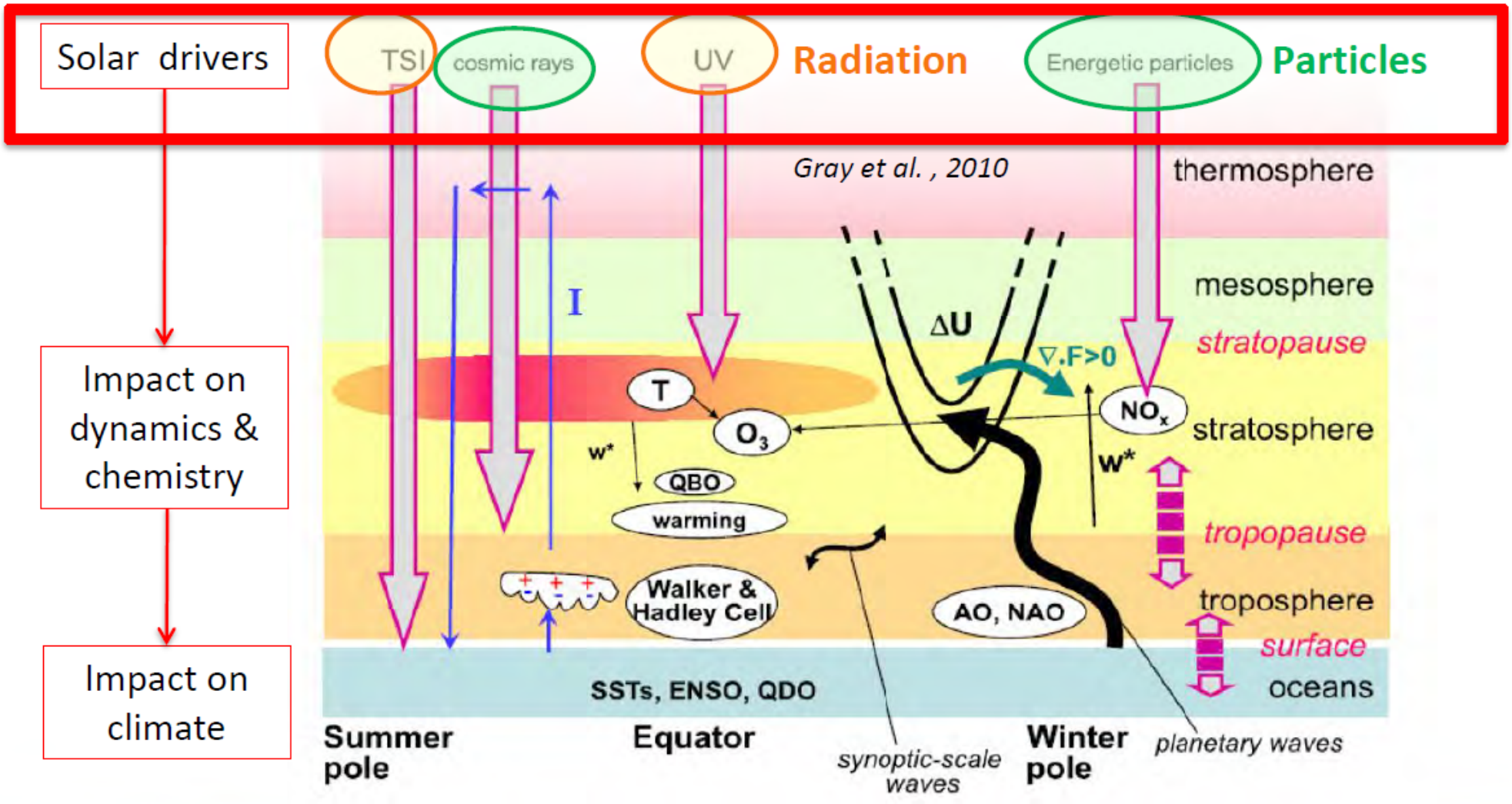
Mesosphere

Stratosphere - ozone

Dynamical formations in the troposphere

Weather / Climate

Ozone and Circulation



(Matthes, Funke / SPARC General Assembly 2014, Queenstown, New Zealand)

Dynamical formations in the troposphere ⟺ **Weather / Climate**

Stratosphere-troposphere:

Stratosphere-troposphere connections:

1. Influence of tropospheric synoptic formations and weather systems on local changes in the stratospheric ozone distribution.

   - identification of local patterns in the stratospheric ozone distribution as the outcome of tropospheric synoptic formations and weather systems

   local ozone anomalies – "mini-holes" and "mini-highs"

2. Influence of stratospheric ozone distribution on features of general circulation in the troposphere (?)

   long-term weather patterns / regional climate

1. General Circulation

Influence of stratospheric ozone distribution on features of general circulation in the troposphere (?)

long-term weather patterns / regional climate

Analysis of:

- **instantaneous global state** of atmospheric general circulation instead of its **monthly, seasonal, yearly or other longtime means**
- **dynamics at finest time resolution available (analysis 4/day)**
- **global circulation instead of its zonal or meridional averages**

- Interaction between the stratospheric ozone layer and tropospheric global air masses:
  - Objective determination of position and structure of ***stationary (upper-level) frontal zones***
    - ***Parameters of global (planetary-scale) circulation cells (air-masses)***

2. Local ozone anomalies

- *Local ozone anomalies*, defined as synoptic-scale deviations in the total ozone column field with a characteristic lifetime of a few days, have been a subject of intense research involving analysis of various observational data and global-scale transport modelling studies

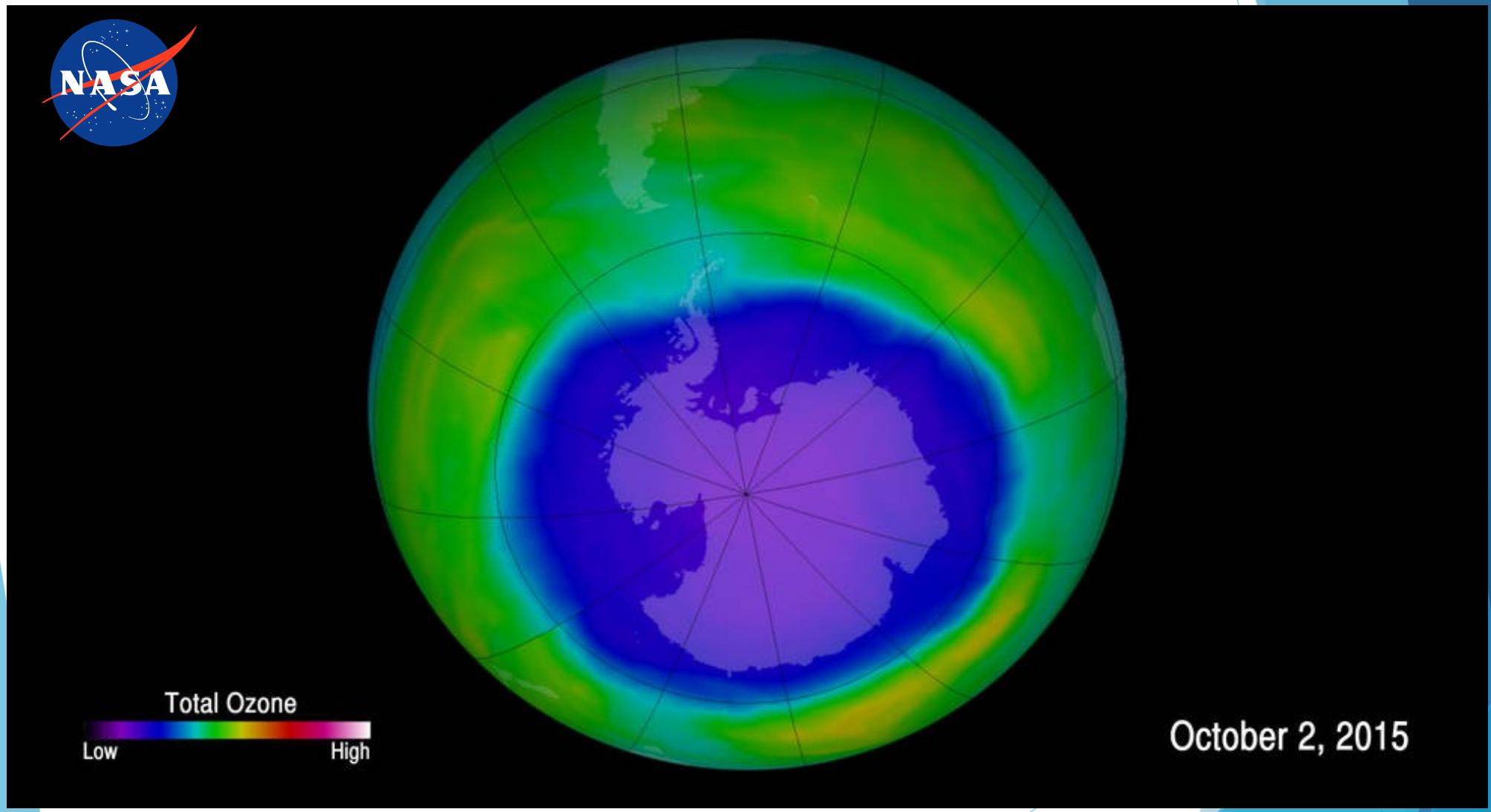
- Synoptic-scale positive or negative deviations in the total ozone column (TOC), having a characteristic lifetime of about a week or a few days and spanning horizontal sizes of a few hundreds or thousands kilometres

- Universally recognized (?) to be formations of a predominantly dynamical origin

- ***Mini-holes*** (negative) and *mini-highs* (positive)

Ozone mini-holes

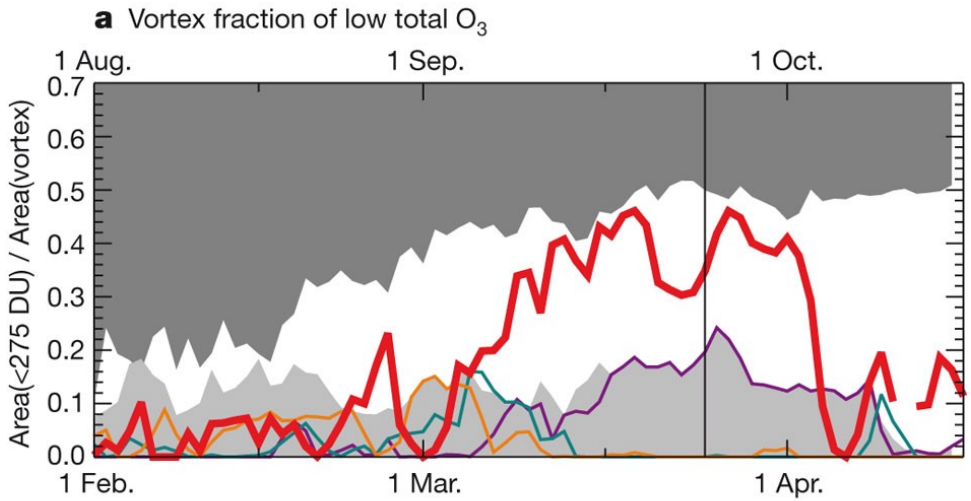
- mini-holes, but not this Hole:



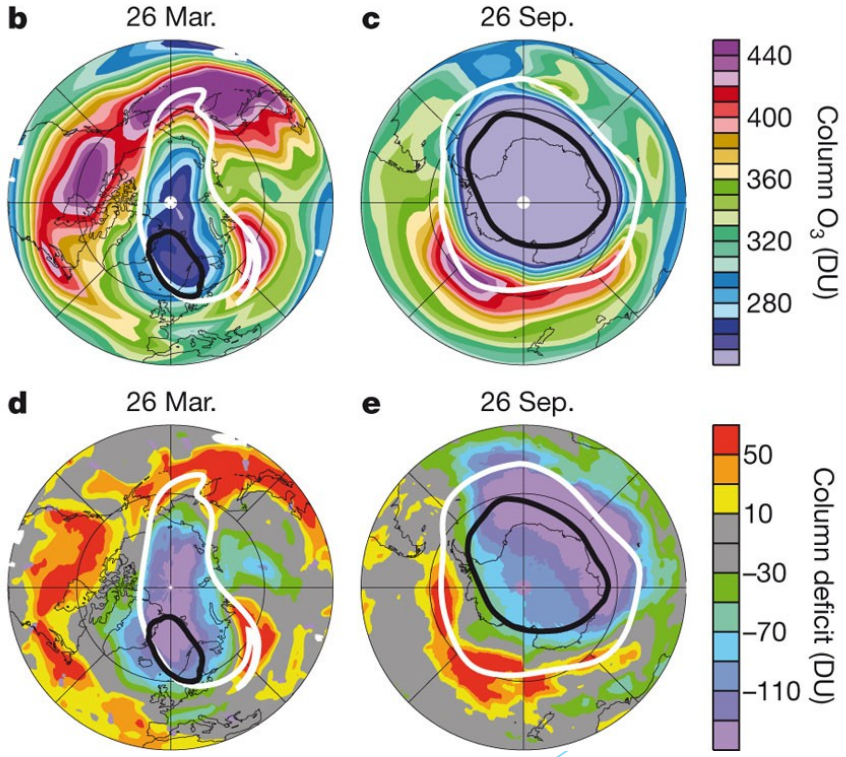
https://www.nasa.gov/feature/goddard/annual-antarctic-ozone-hole-larger-and-formed-later-in-2015

Ozone mini-holes

... And not even this one:



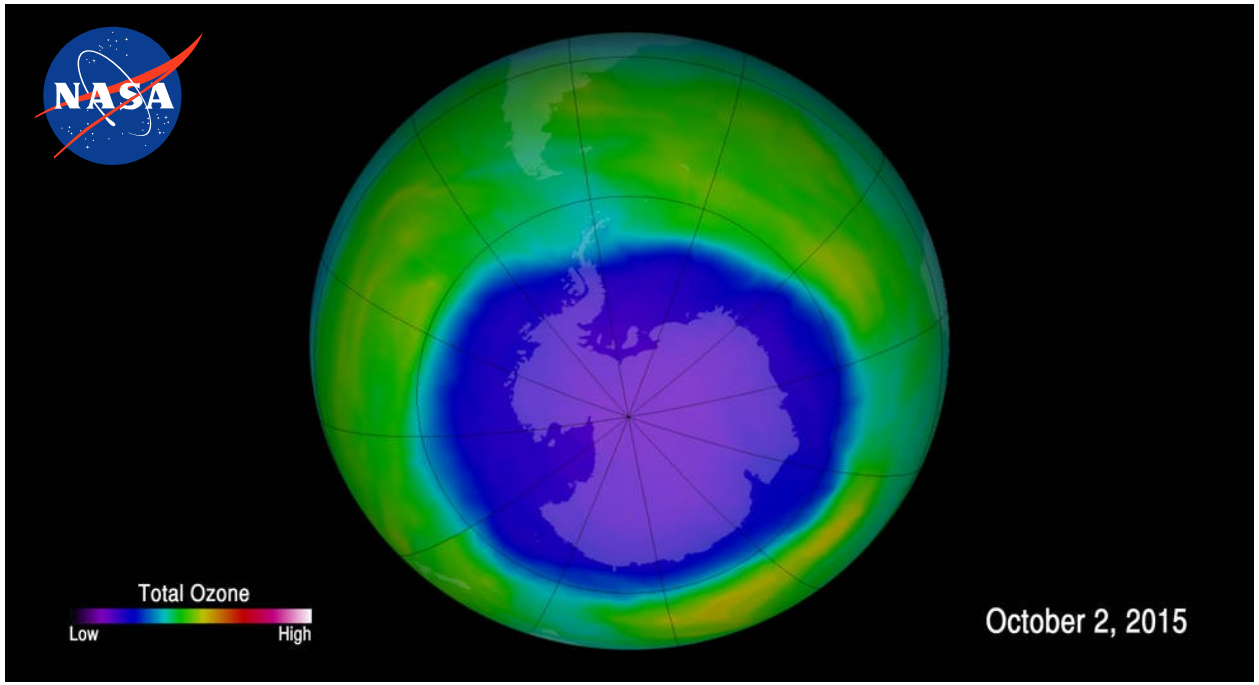
"Unprecedented Arctic ozone loss in 2011"



nature

GL Manney *et al*. *Nature* **000**, 1-7 (2011)
doi:10.1038/nature10556

Ozone impact on circulation



Seasonal ozone hole *does* influence tropospheric circulation / weather

https://www.nasa.gov/feature/goddard/annual-antarctic-ozone-hole-larger-and-formed-later-in-2015

Kang, S., Polvani, L., Fyfe, J., & Sigmond, M. (2011).
Impact of Polar Ozone Depletion on Subtropical Precipitation.
Science, 332(6032), 951-954. http://dx.doi.org/10.1126/science.1202131

Feldstein, S. (2011).
Subtropical Rainfall and the Antarctic Ozone Hole.
Science, 332(6032), 925-926. http://dx.doi.org/10.1126/science.1206834

Ozone-climate connections

Stratospheric ozone → impact on seasonal forecasting

Calvo, N., Polvani, L., & Solomon, S. (2015).
On the surface impact of Arctic stratospheric ozone extremes.
Environmental Research Letters, 10(9), 094003.

Garfinkel, C. (2017).
Might stratospheric variability lead to improved predictability of ENSO events?
Environmental Research Letters, 12(3), 031001.

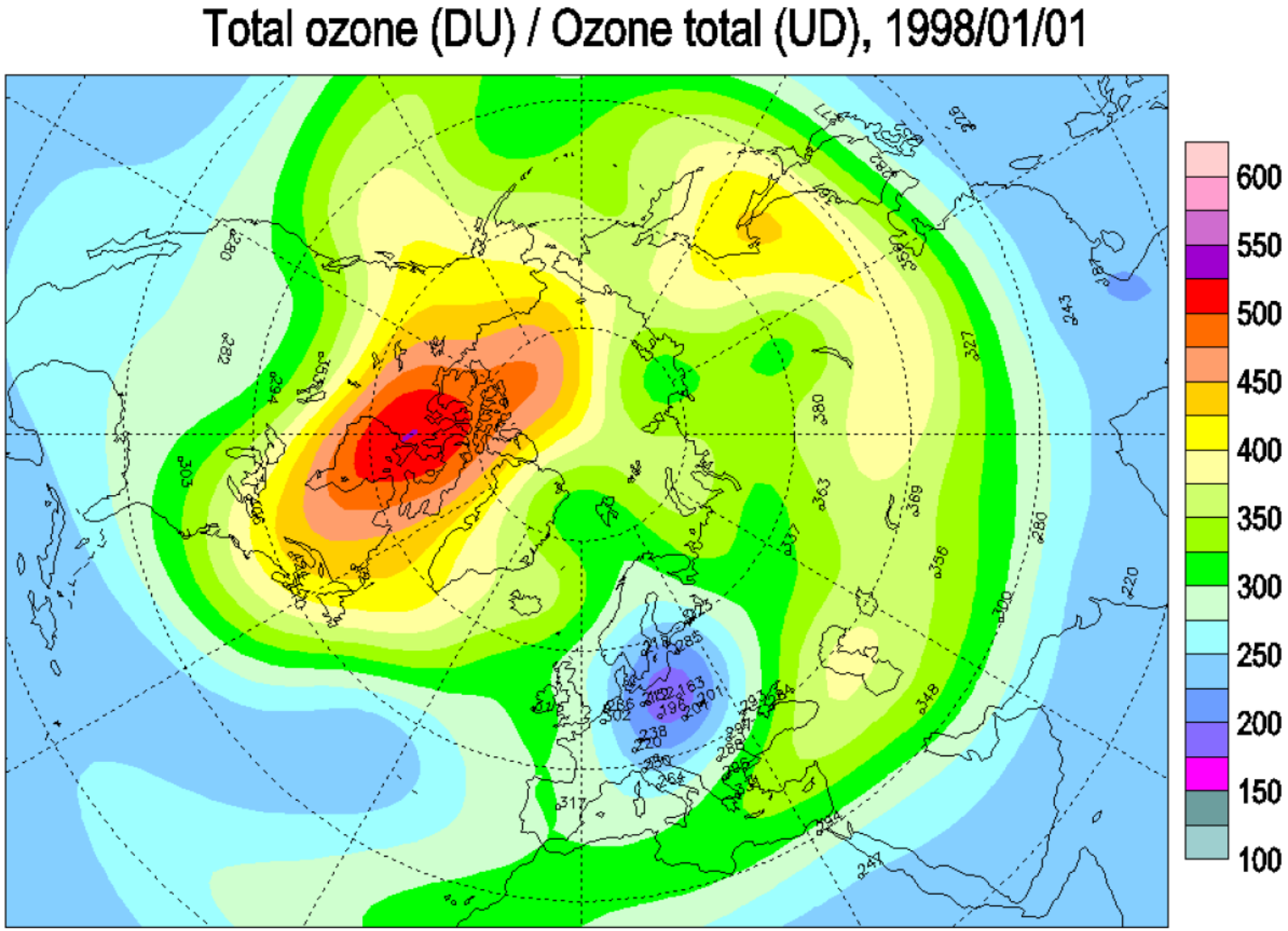
Xie, F., Li, J., Tian, W., Fu, Q., Jin, F., & Hu, Y. et al. (2016).
A connection from Arctic stratospheric ozone to El Niño-Southern oscillation.
Environmental Research Letters, 11(12), 124026.

Smith, K., & Polvani, L. (2014).
The surface impacts of Arctic stratospheric ozone anomalies.
Environmental Research Letters, 9(7), 074015.

Ineson, S., & Scaife, A. (2008).
The role of the stratosphere in the European climate response to El Niño.
Nature Geoscience, 2(1), 32-36.

Local ozone anomalies

Ozone mini-holes cases – Dec 1997 – Jan 1998



Environment Canada (http://exp-studies.tor.ec.gc.ca/)

Local ozone anomalies

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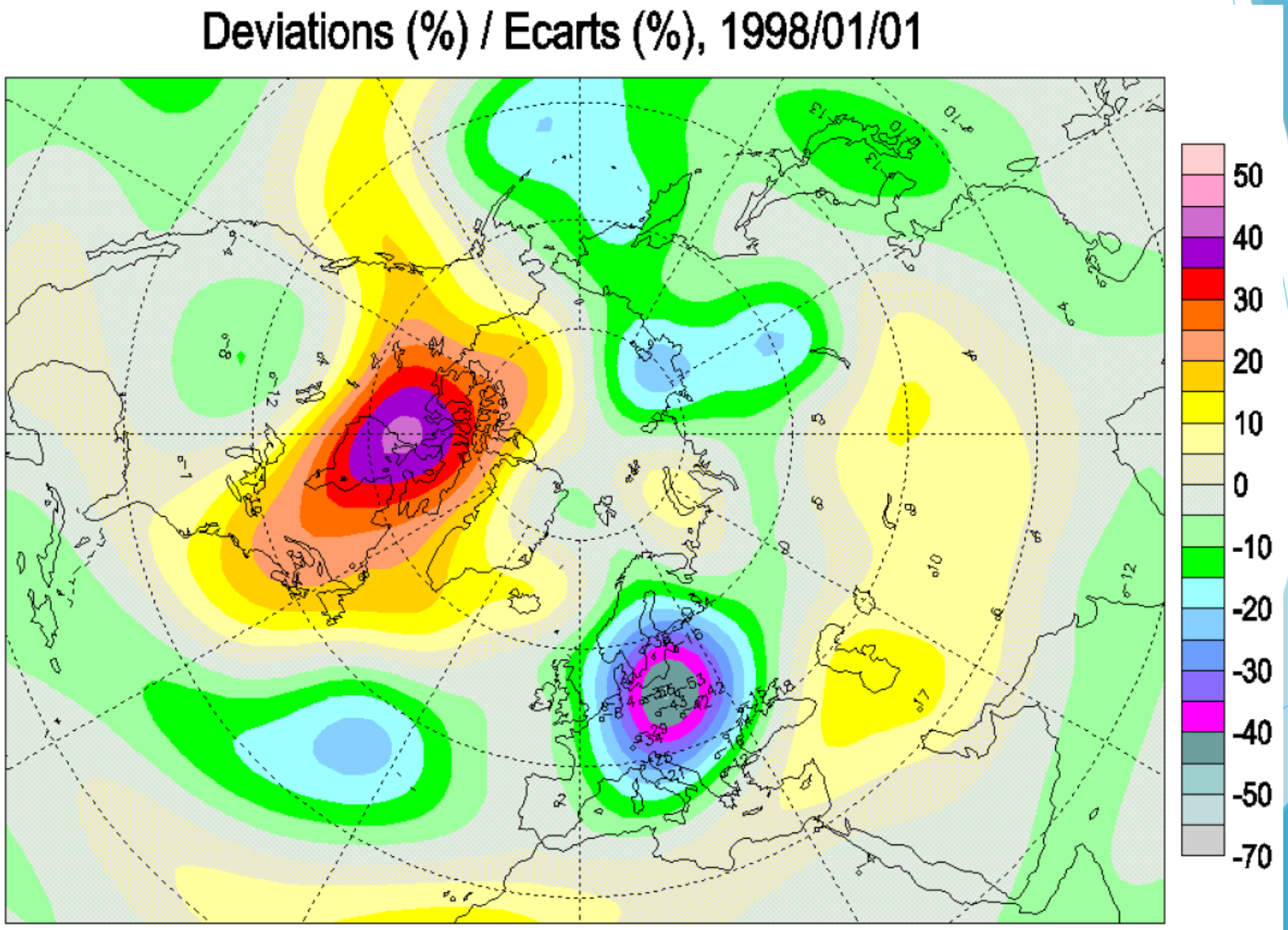


Environment Canada (http://exp-studies.tor.ec.gc.ca/)

Local ozone anomalies

Objective identification and tracking of local ozone anomalies

→ *Statistics / catalog of all local ozone anomalies for a given period*

- Perspectives for application of image processing / recognition algorithms (objective features detection, etc. …)

→ ***objective*** *features extraction in different geoscientific data fields*

T.D. Hewson
Objective fronts
Meteorol. Appl., 5, pp. 37–65, 1998.

S. Limbach et al
Detection, tracking and event localization of jet stream features in 4D atmospheric data
Geosci. Model Dev., 5, 457-470, 2012.

- Different definitions of local ozone anomalies exist **!**

Local ozone anomalies

Identification and tracking:

Definition of local ozone anomalies:

- usually one considers deviations of the total ozone field from its "normal distribution", which can be defined in different ways.

→ Total ozone values with a deviation from the "normal" values greater than a specified threshold
→ Contiguous region on the map,
→ Consecutive time steps of the anomaly should have spatial overlap

→ Subsequent filtering of "spurious" anomalies: threshold minimal values of maximal area and time duration

Local ozone anomalies

A possible approach to analysis

Data sources:
MACC / ERA-Interim reanalysis data

Two options for the "normal distribution" of ozone:
- 30-day running averaging of the same data (MACC or ERA-Interim).
- ERA-Interim daily "climatological average" over 1979-1990 period combined with a 30-day running averaging filter.
(90-day averaging gives qualitatively similar results)

Thresholds:
20% deviation
4 grid points area (at 0N latitude, with correction for higher latitudes)
24 hours duration (4 time steps in reanalysis with 6 hour interval)

Accordingly, anomalies with smaller deviation, area or time duration are filtered out.

Local ozone anomalies

A possible approach to analysis

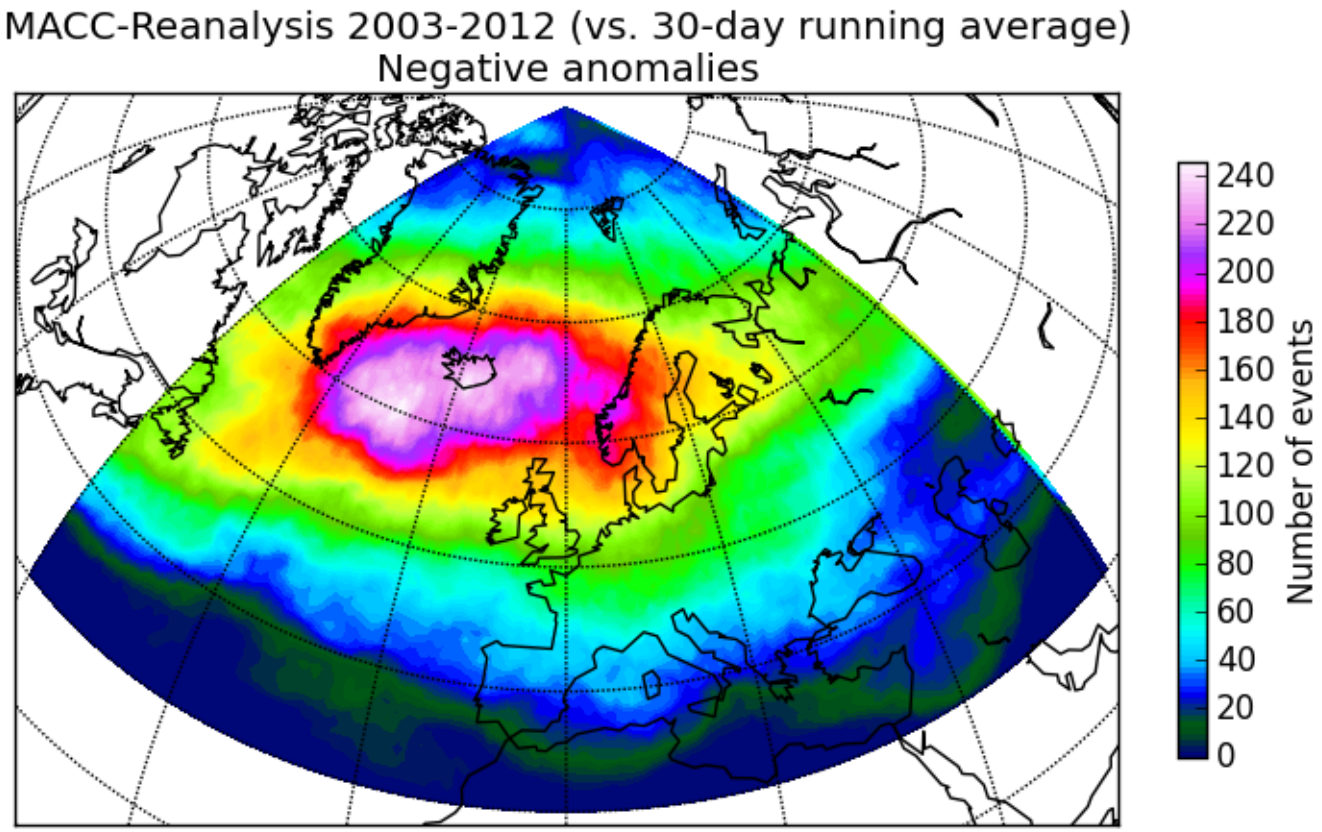
Analysis is applied to a spatial region of **30N – 90N, 60W – 60E**.

For MACC data, time period of 2003-2012 is analysed (MACC-Reanalysis dataset, 10 years).

ERA-Interim data is processed for the time period of 1991-2016 (25 years), so there is no time overlap with the 1979-1990 period used to define the “normal ozone distribution”.

Local ozone anomalies

Spatial distribution of local ozone anomalies events



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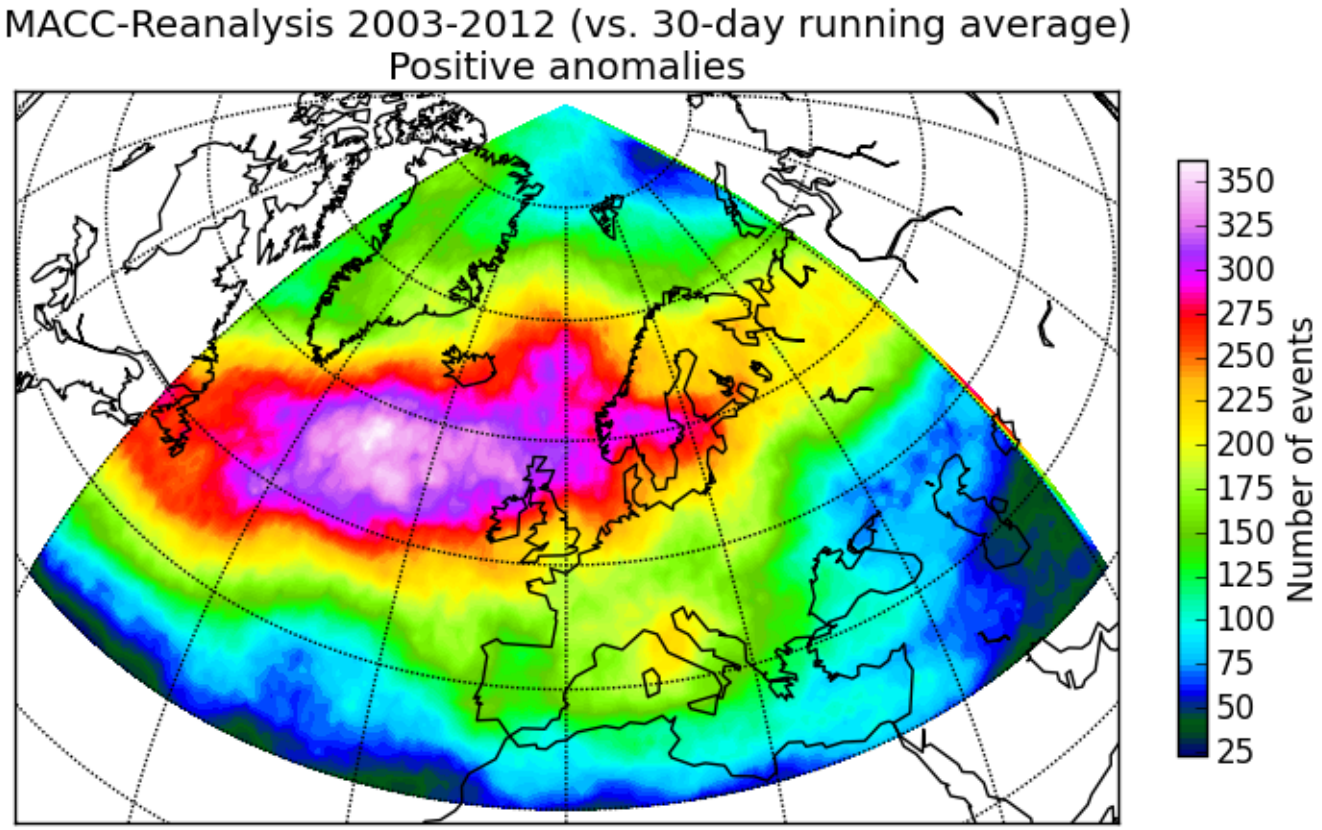

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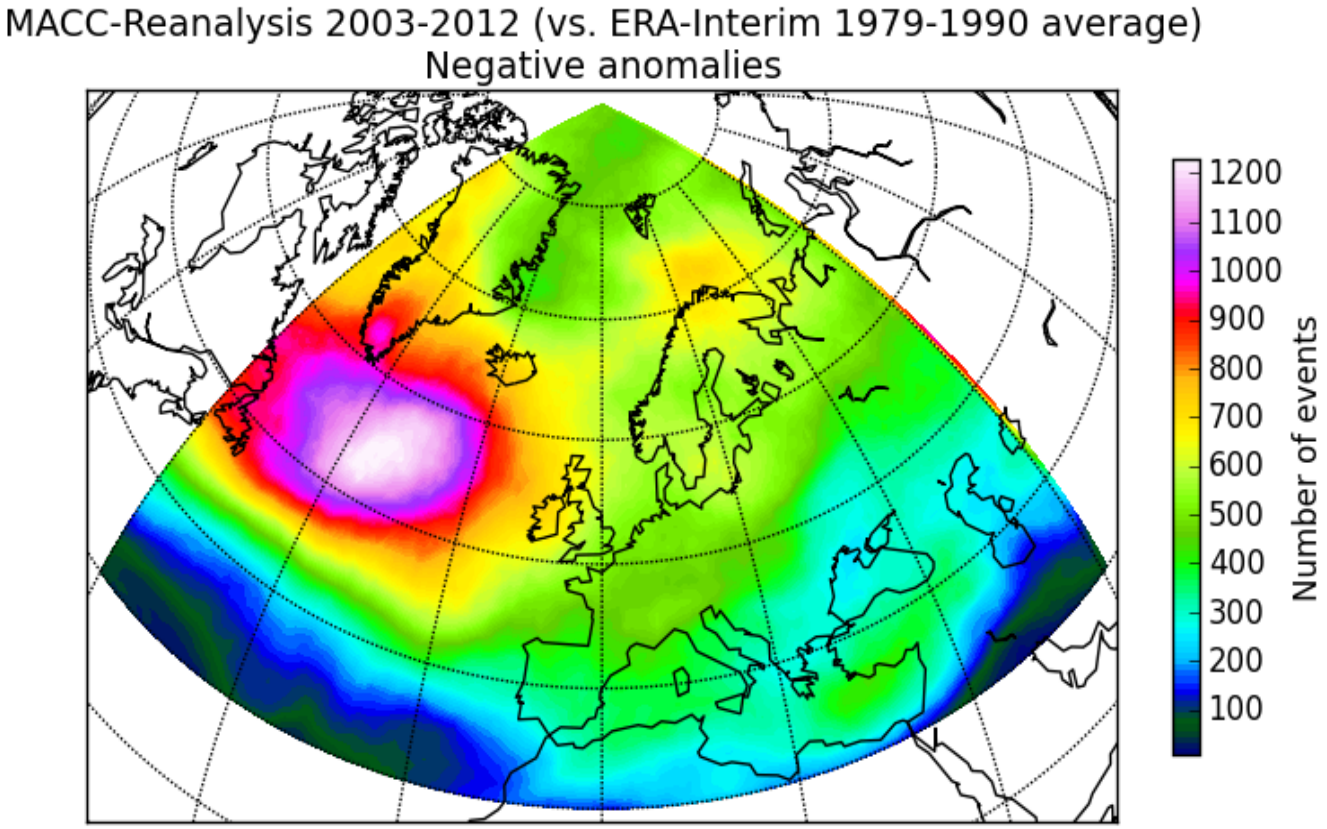

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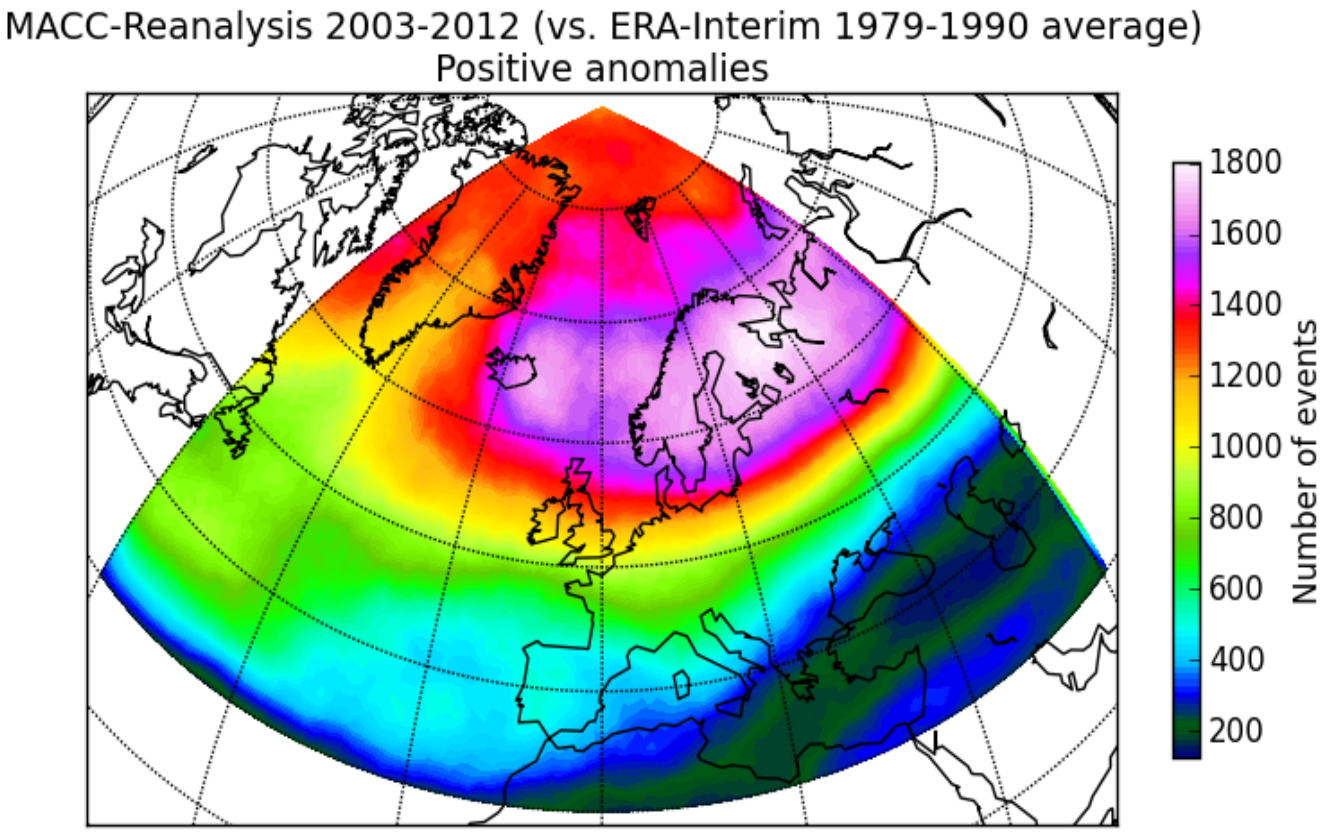

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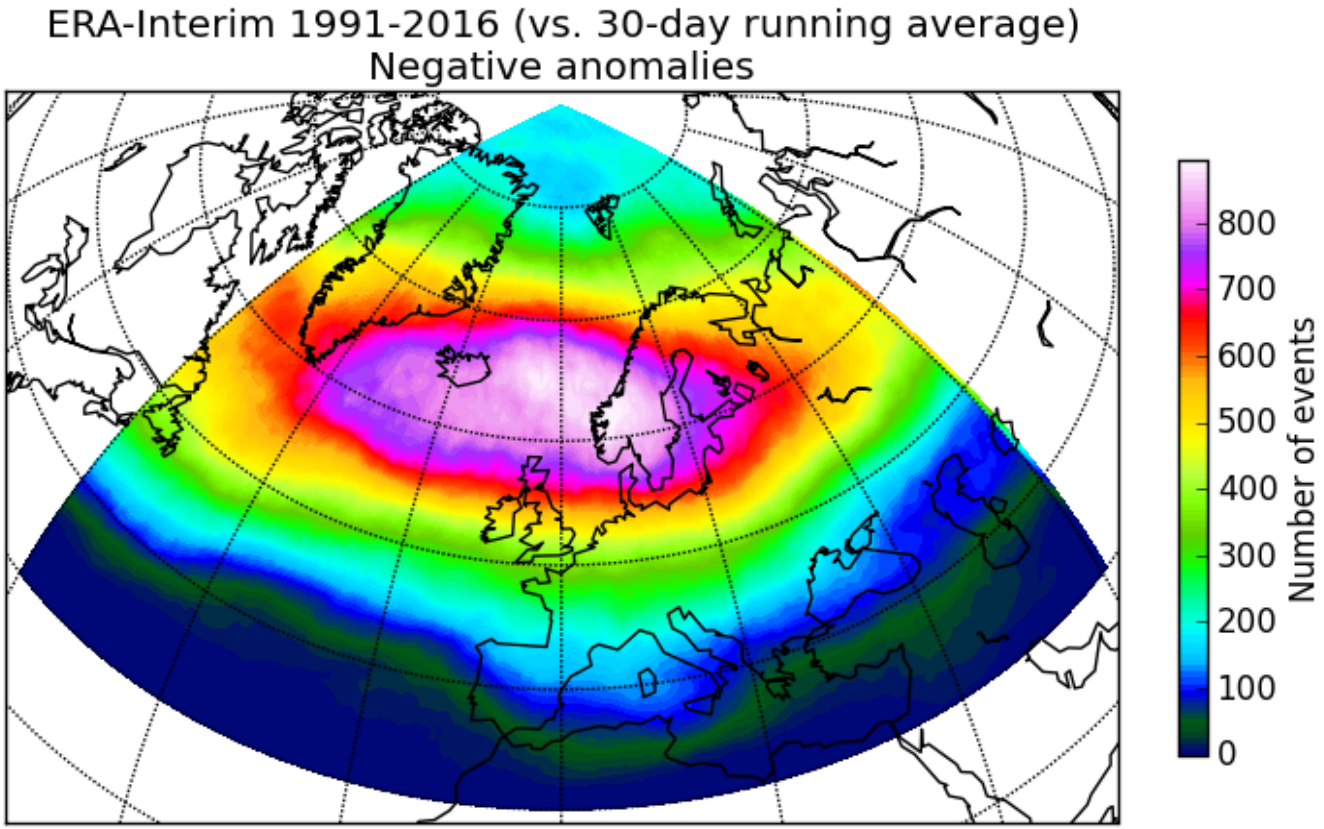

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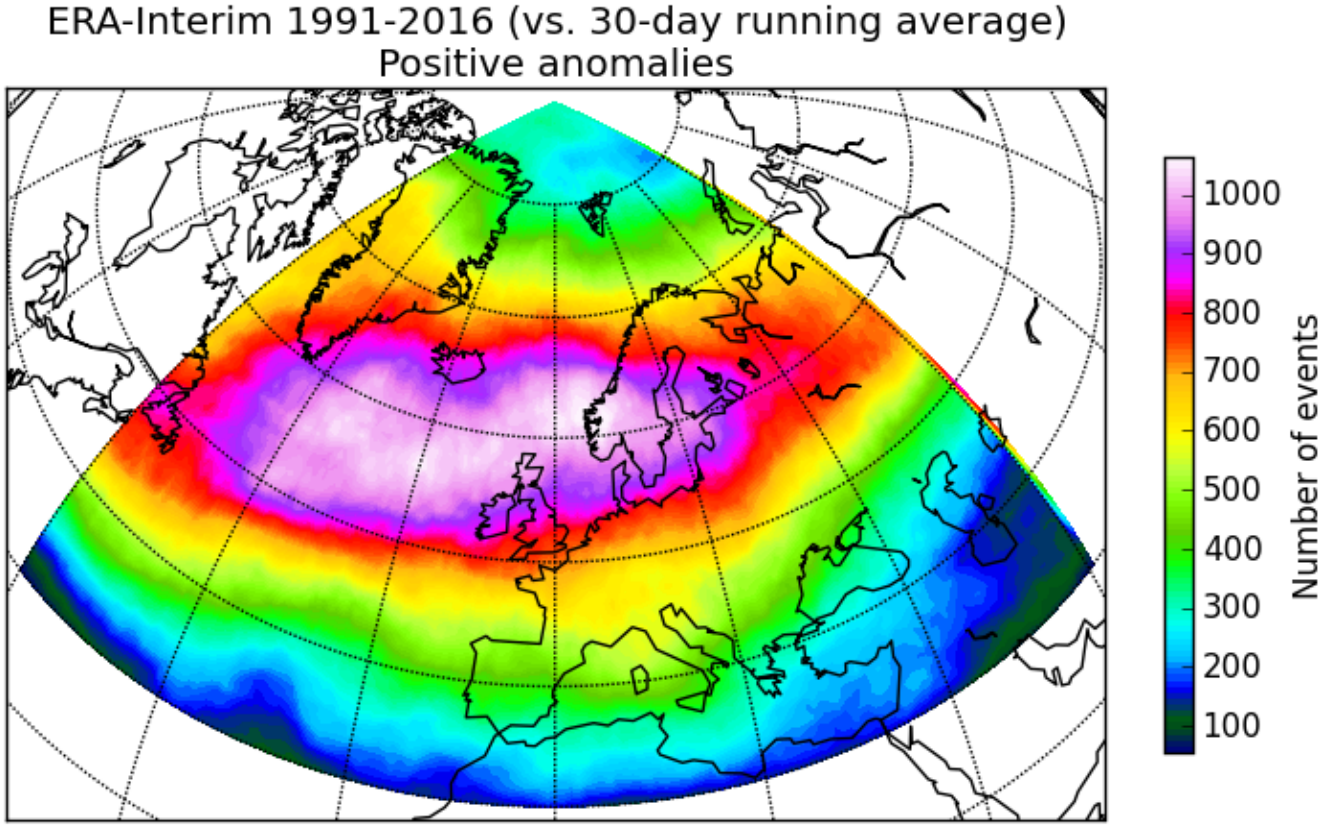

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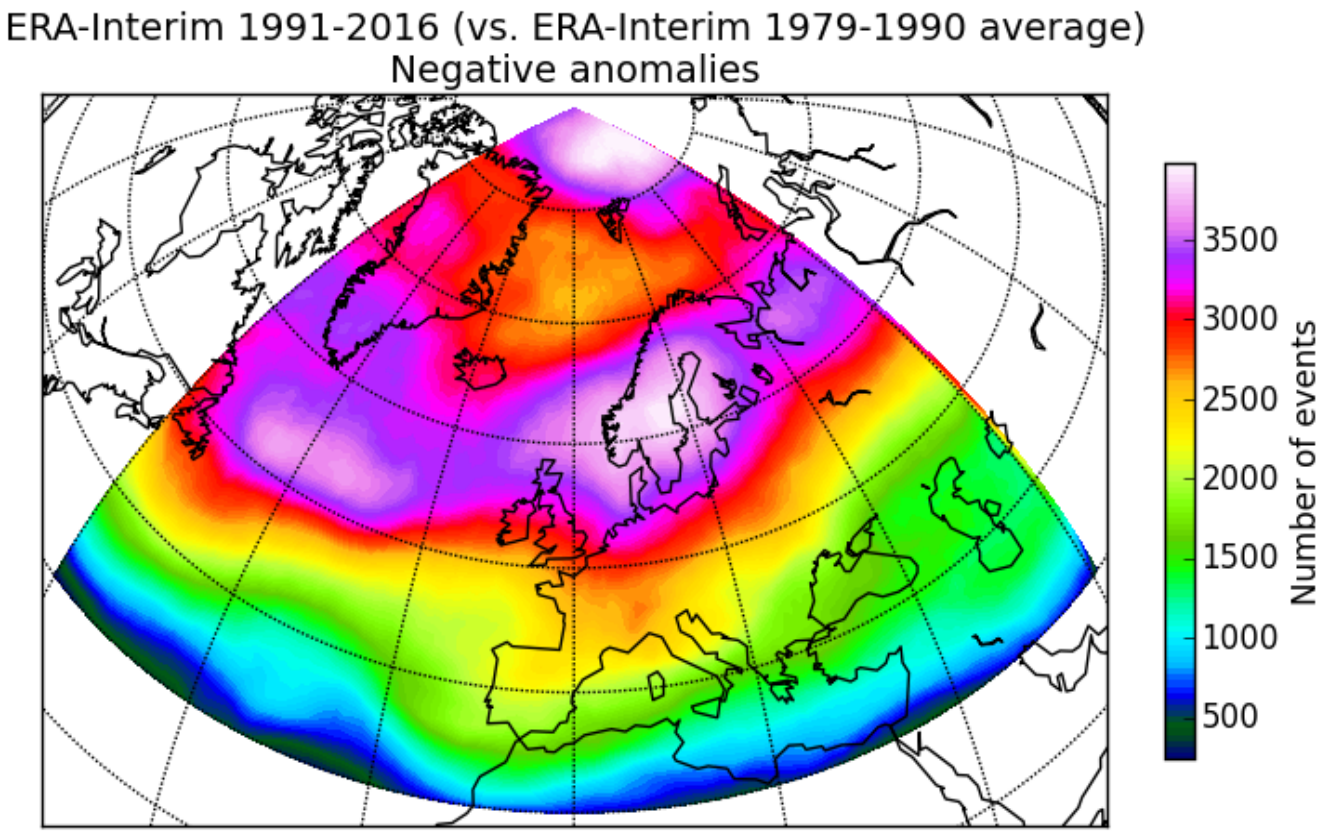
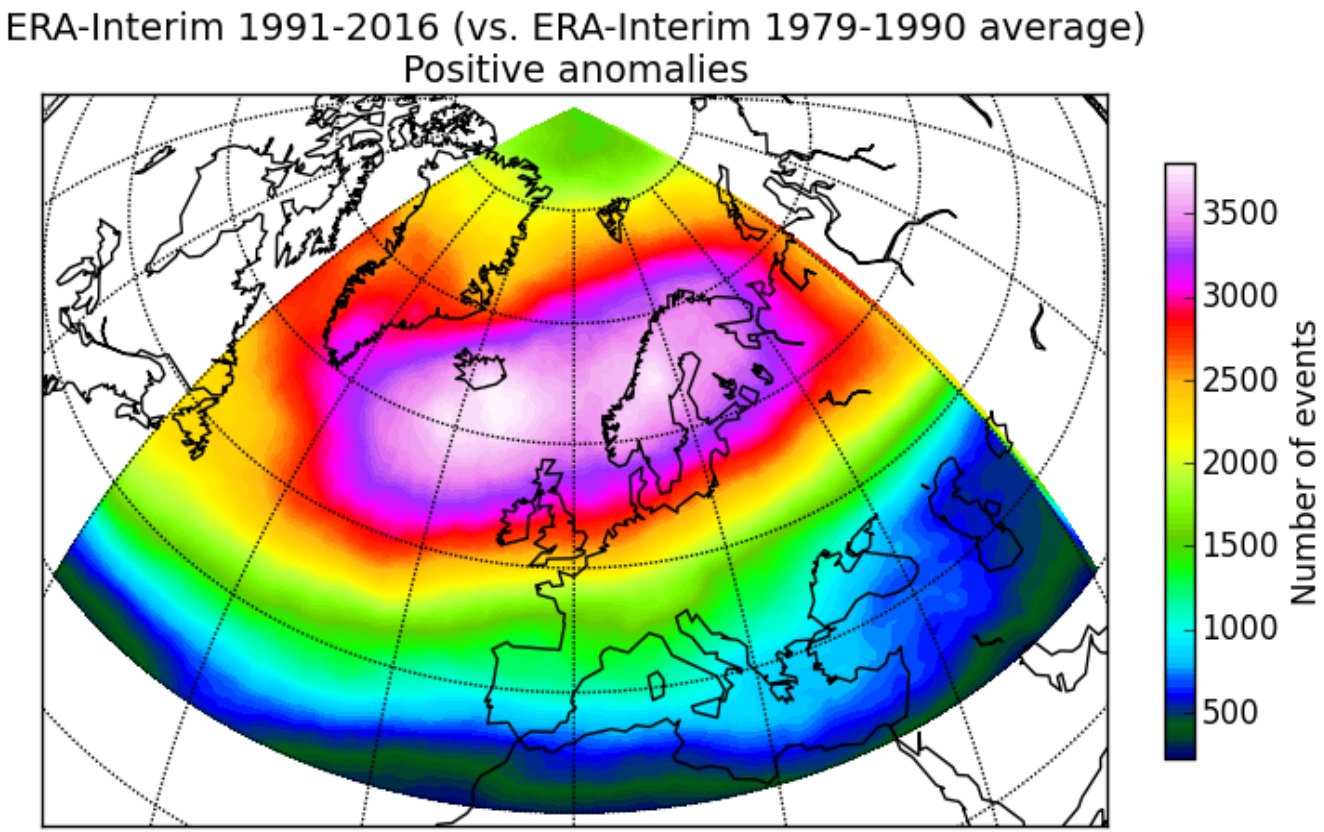


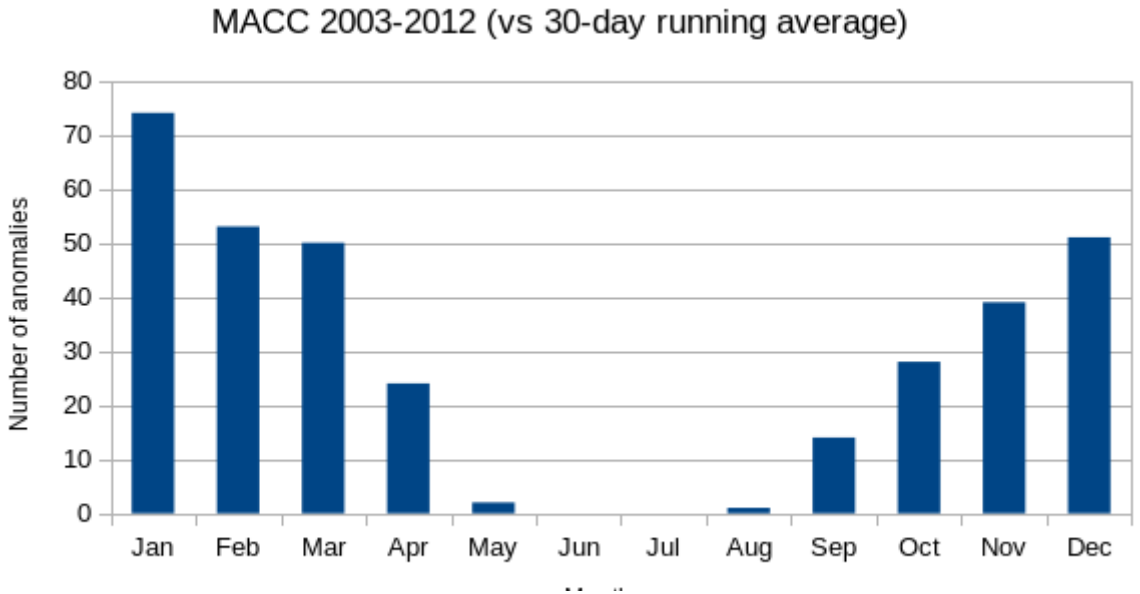
Local ozone anomalies

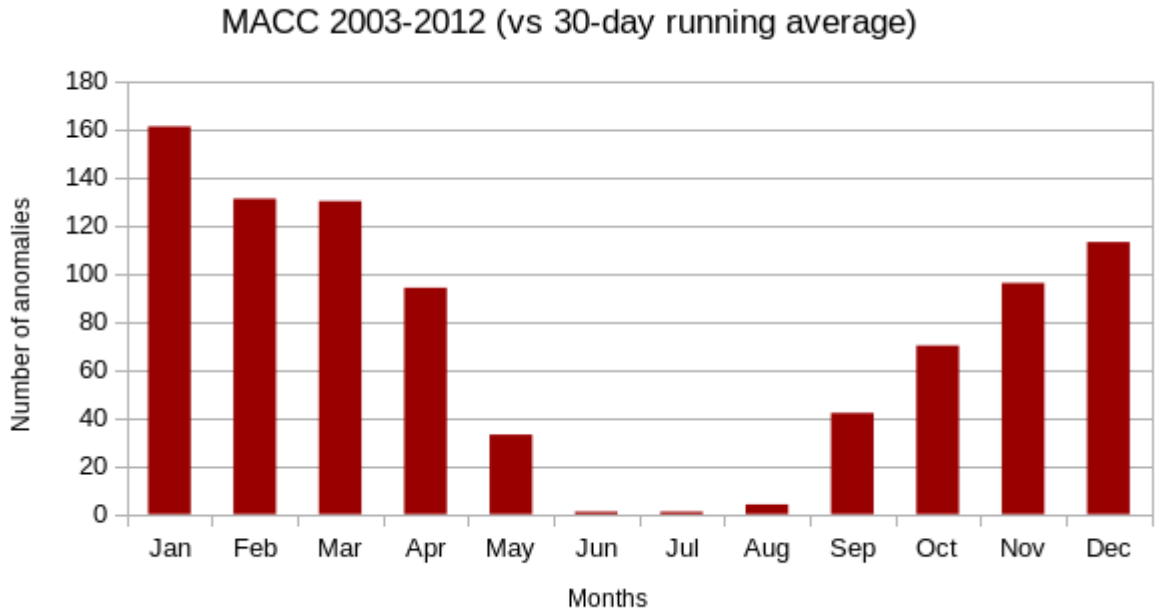
Spatial distribution of local ozone anomalies events



Local ozone anomalies

Temporal distribution of local ozone anomalies events





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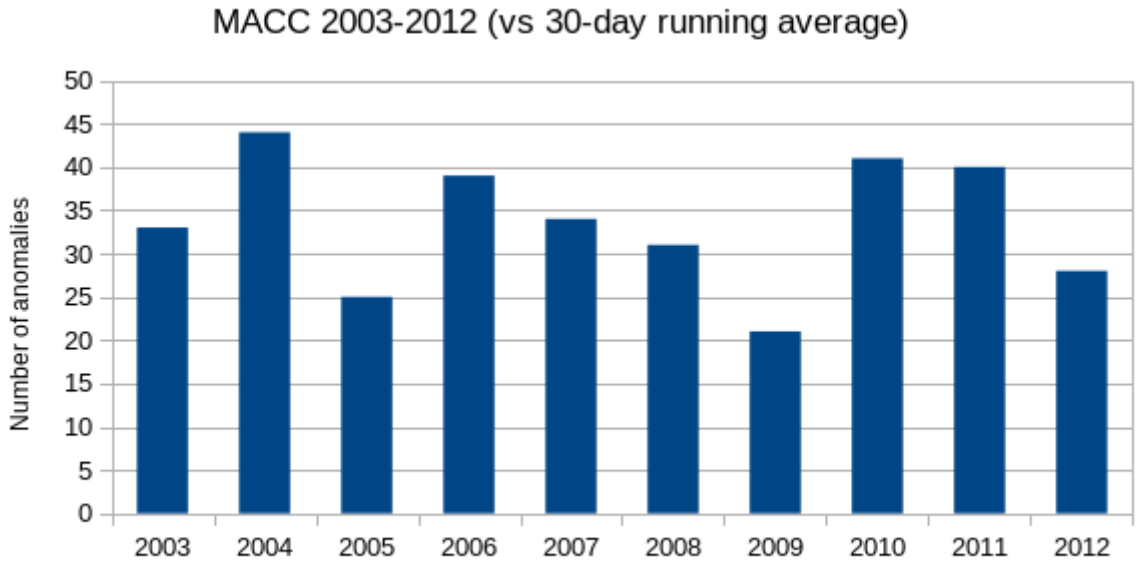
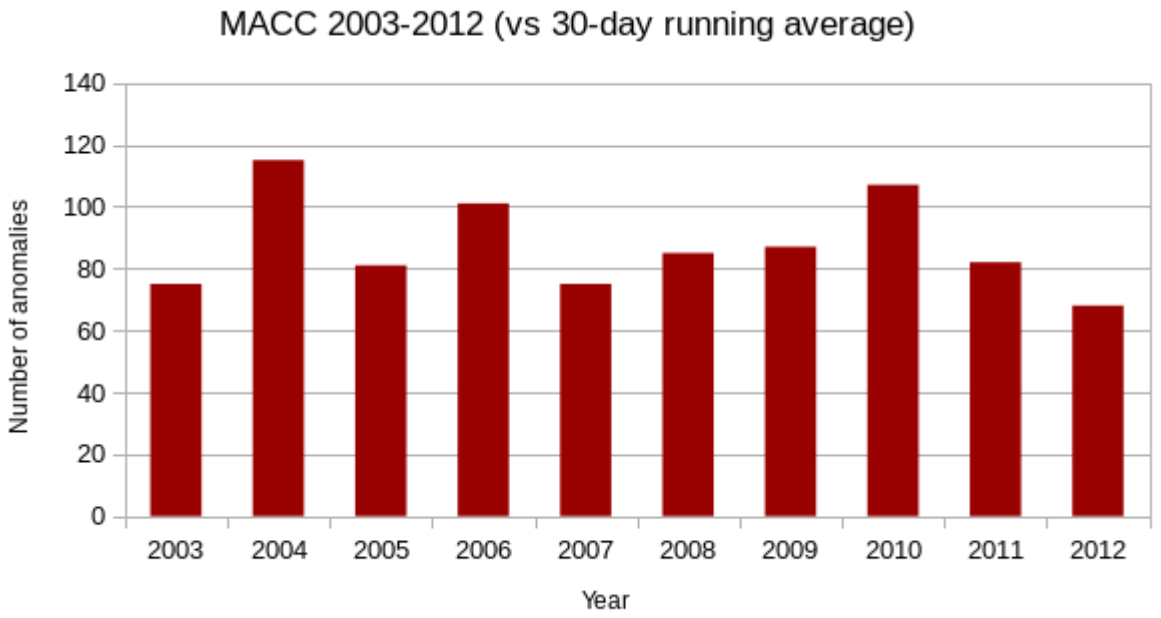




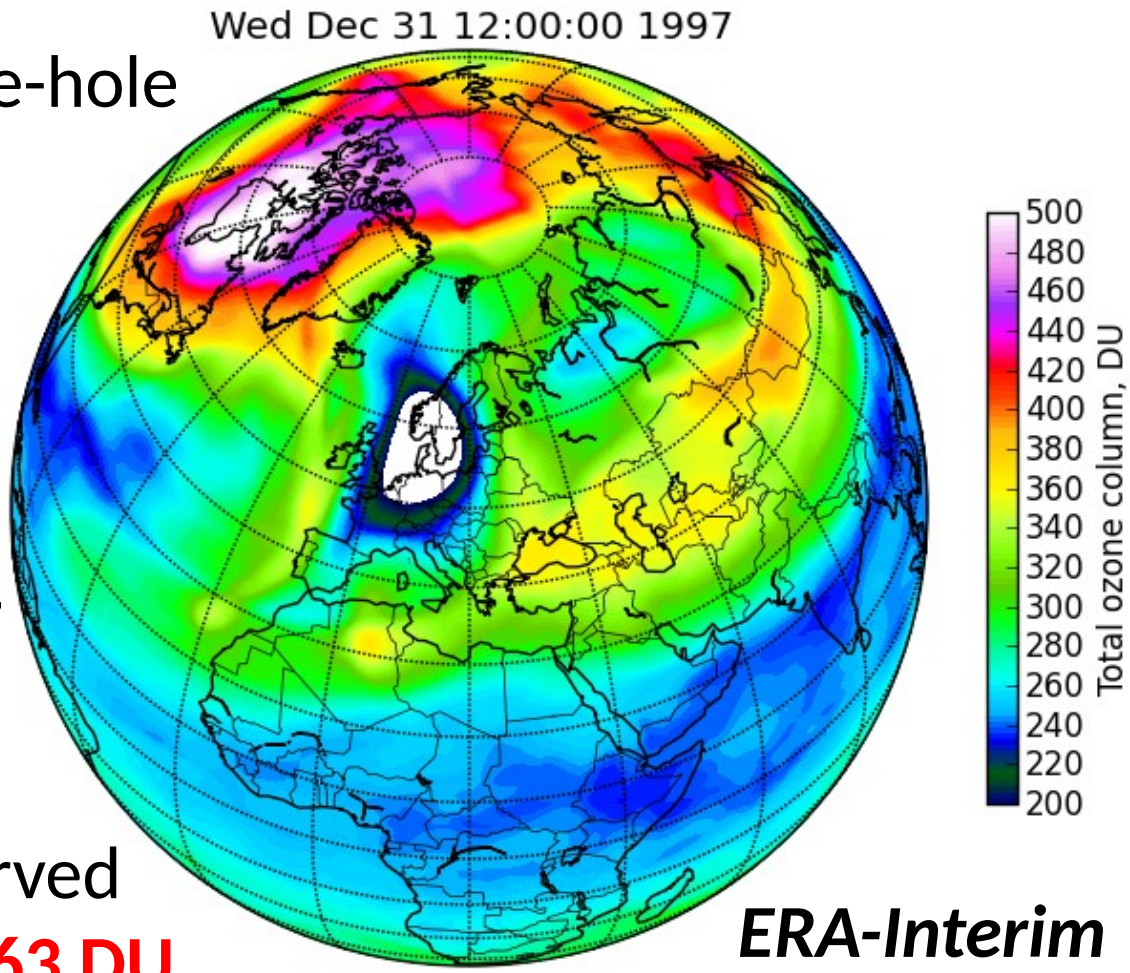
Local ozone anomalies

Case I – Dec 1997 – Jan 1998

Deepest ozone-hole ever observed over Belarus

30 Dec 1997 – 1 Jan 1998

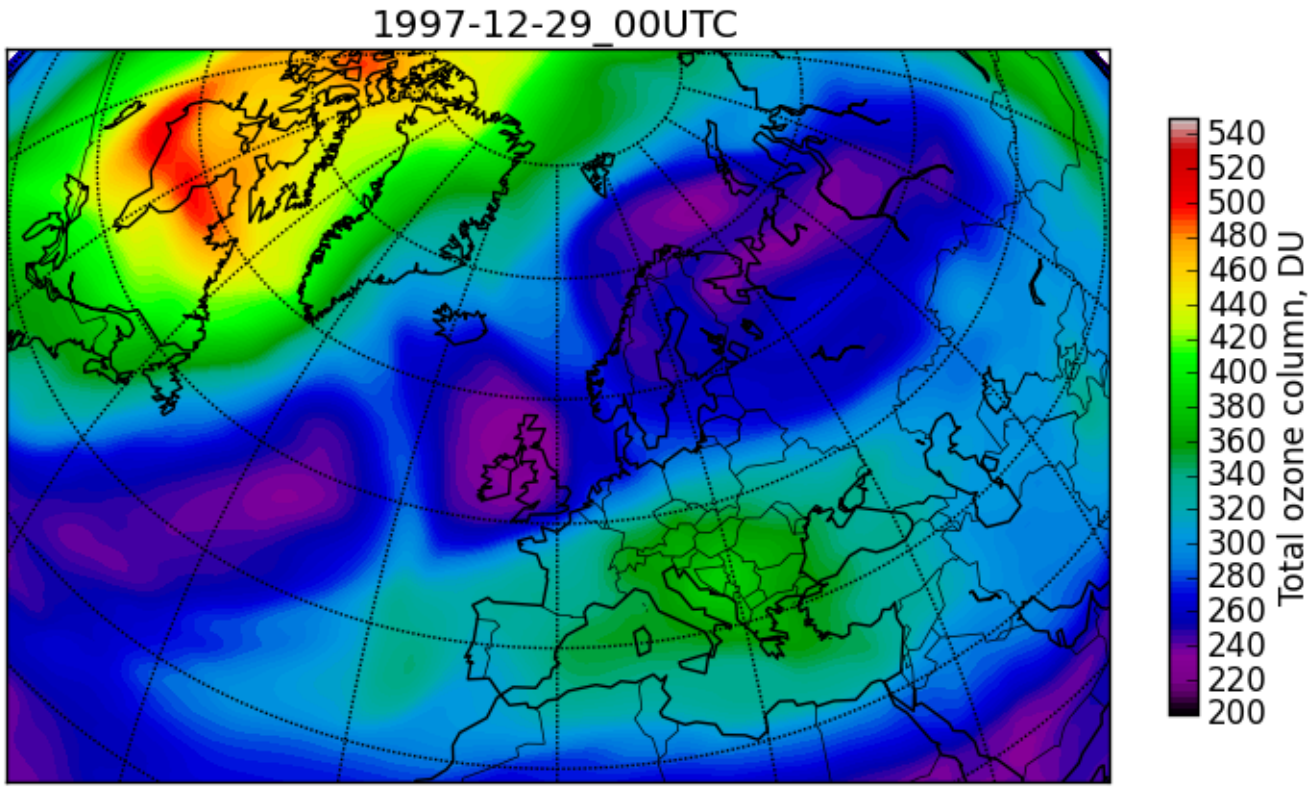
Minimal observed total ozone: **163 DU**



ERA-Interim

Case I (Dec 1997 – Jan 1998)

Total ozone column (DU), ERA-Interim



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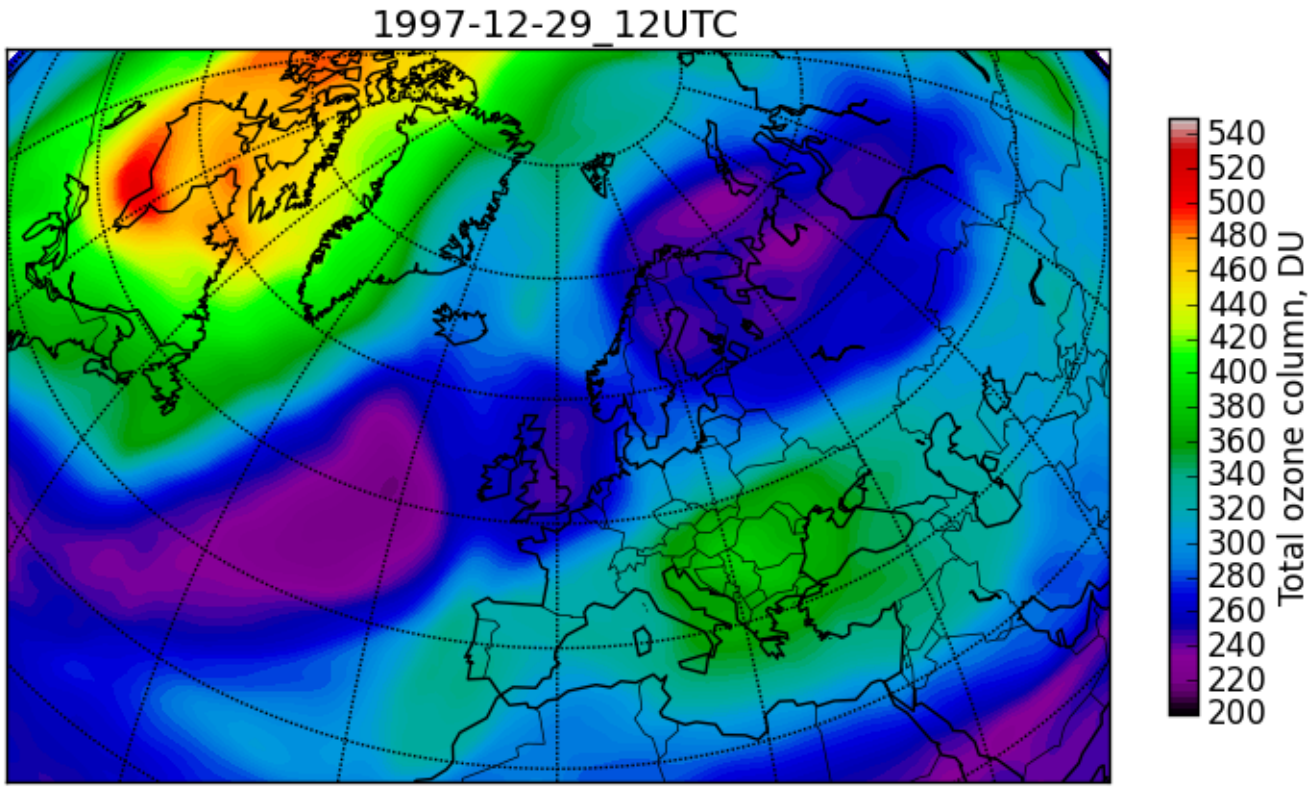

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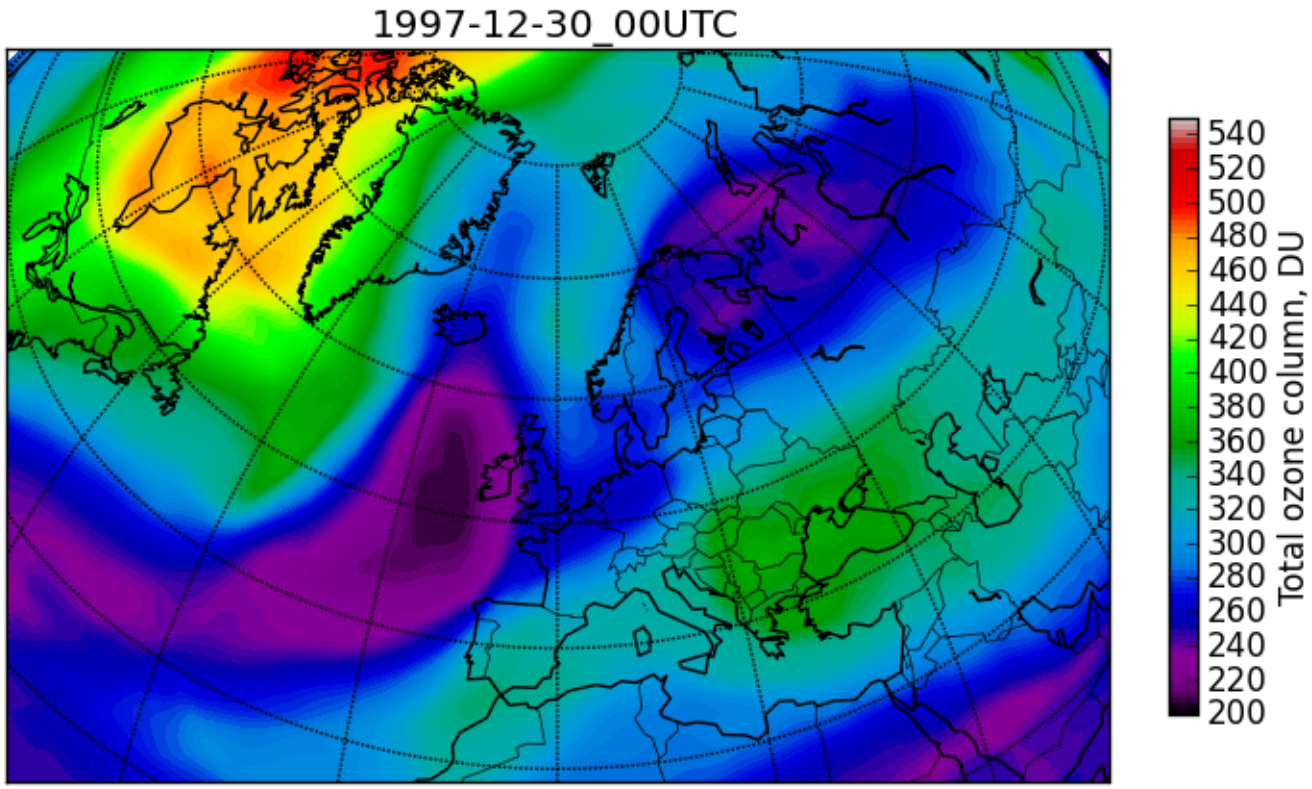

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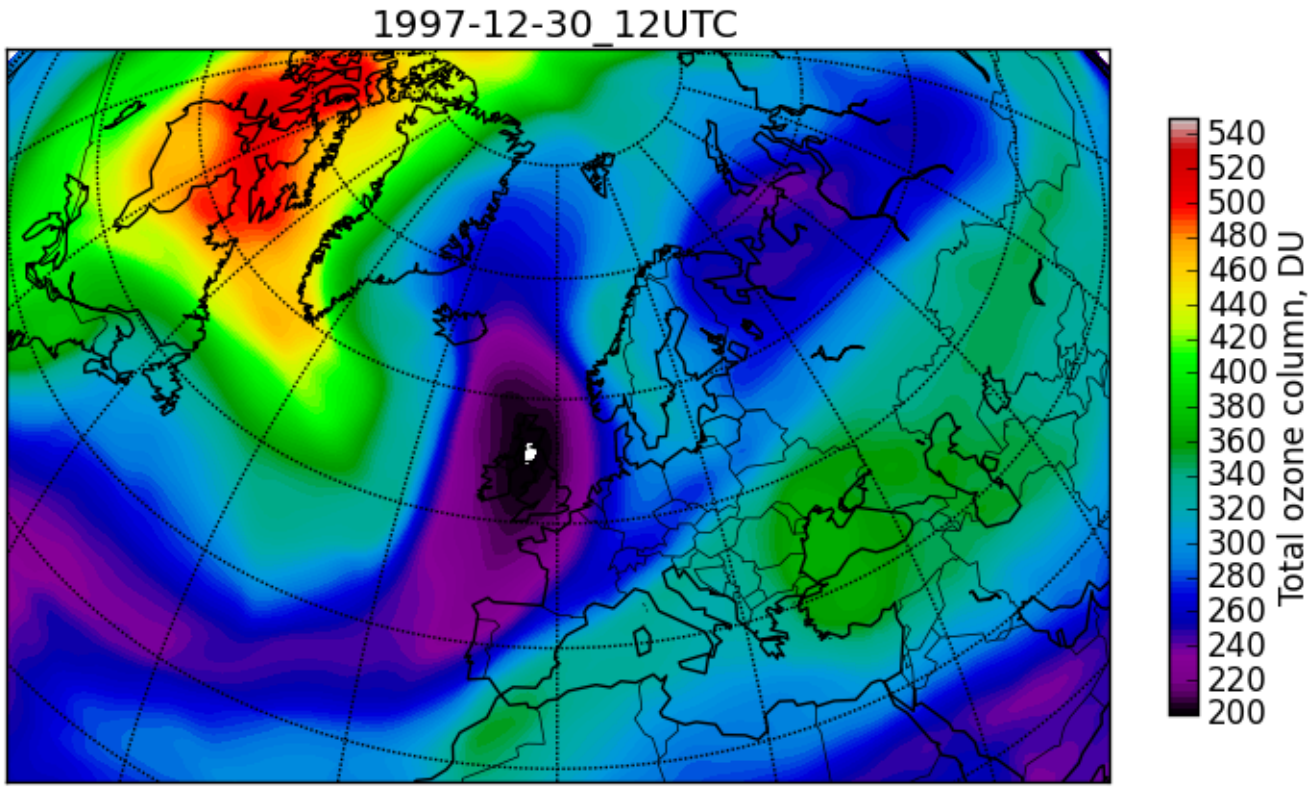

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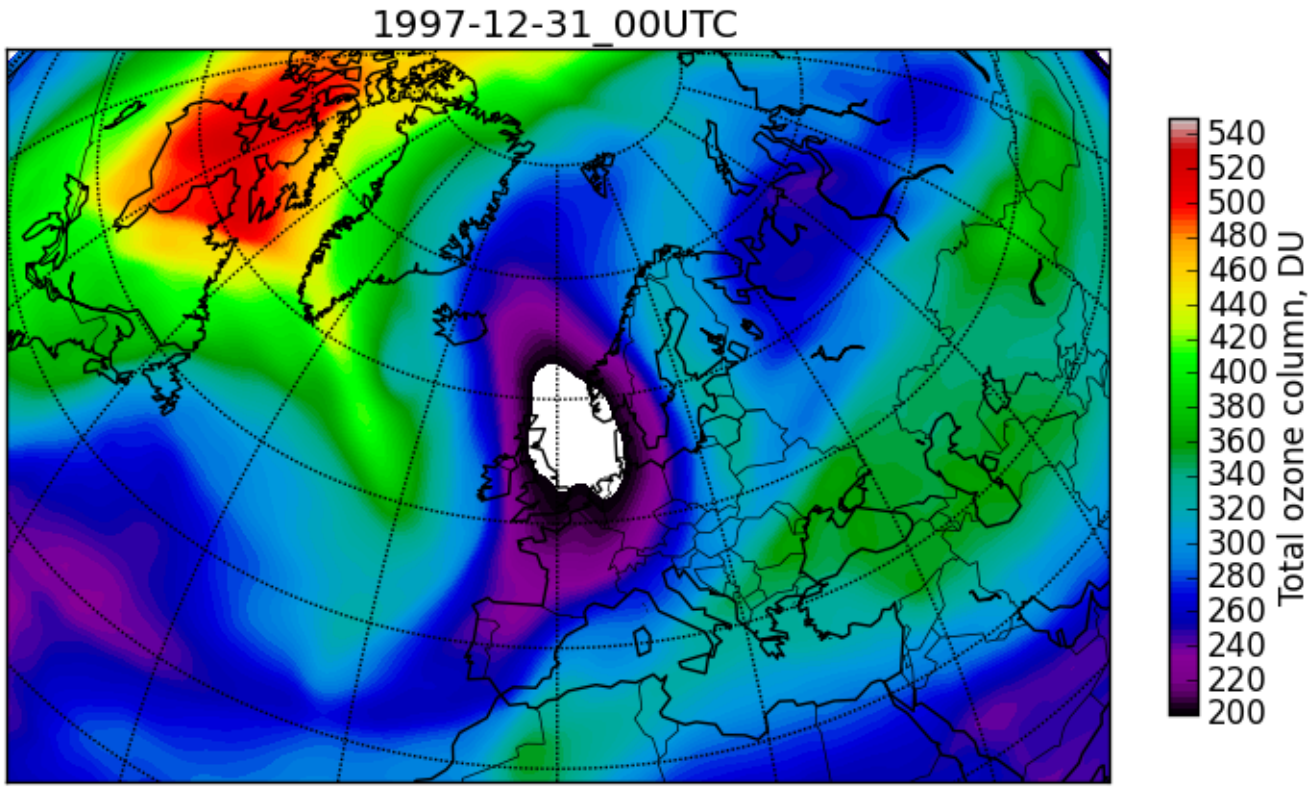

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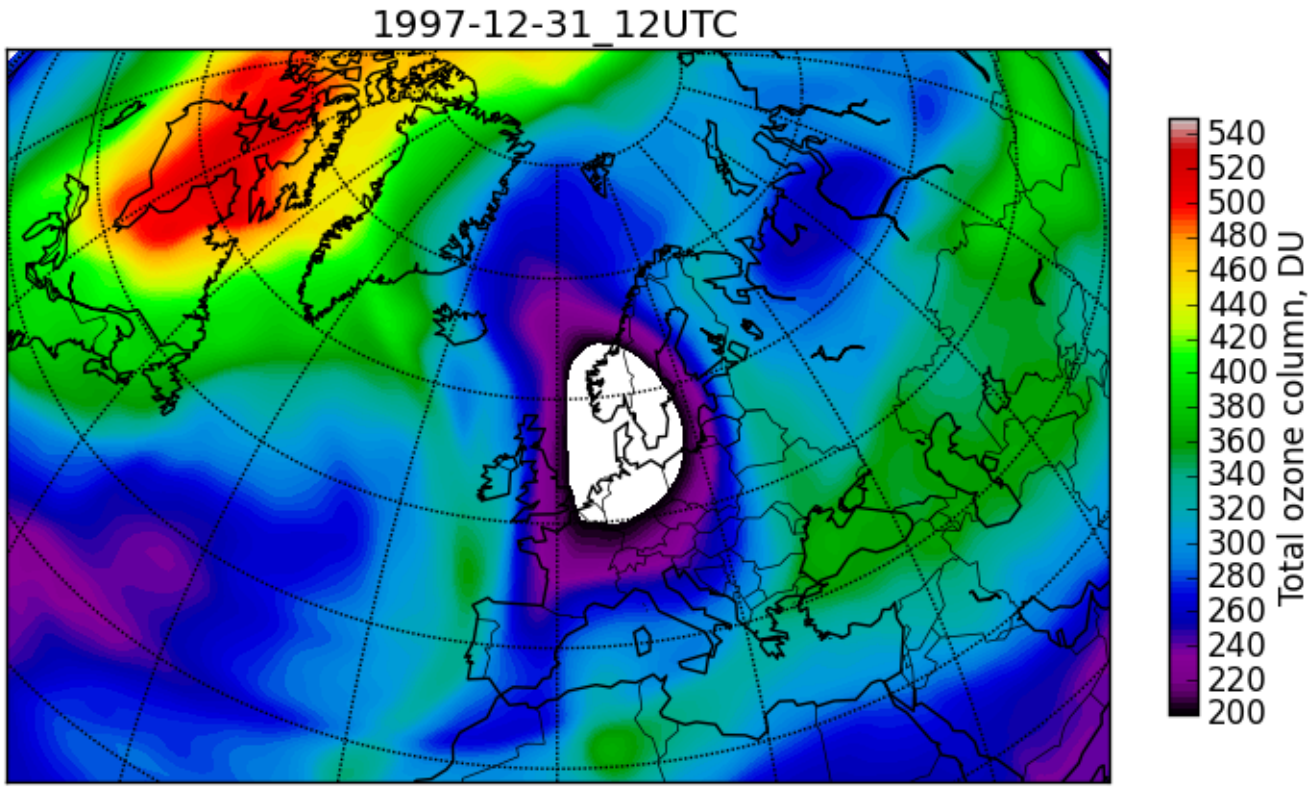

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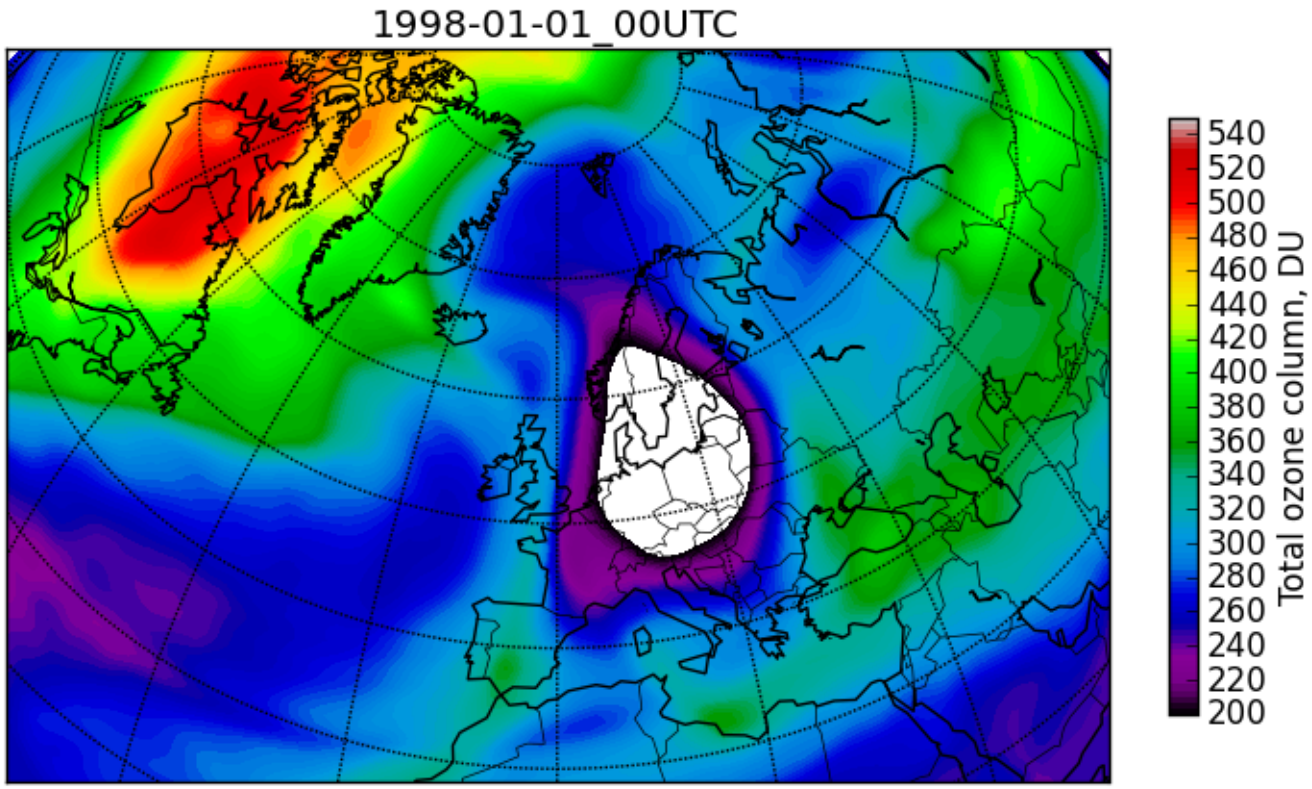

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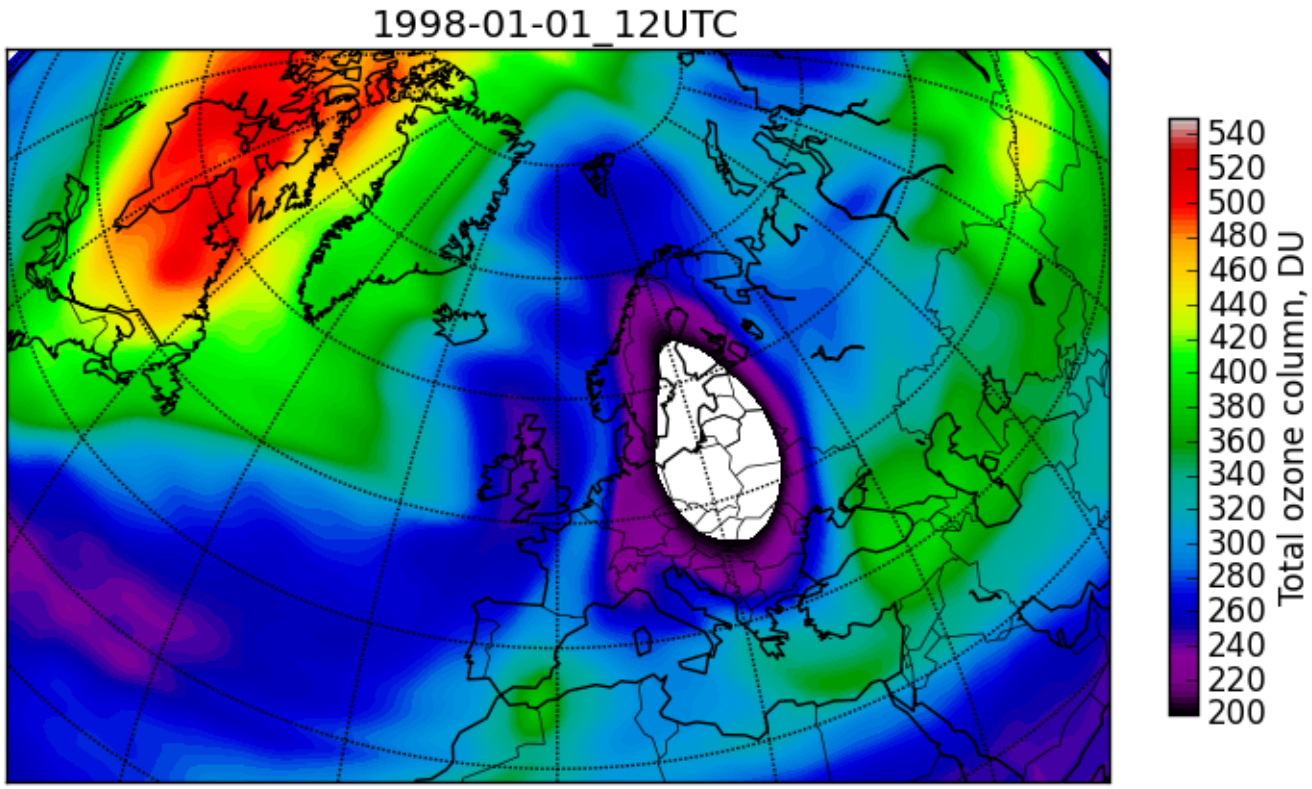
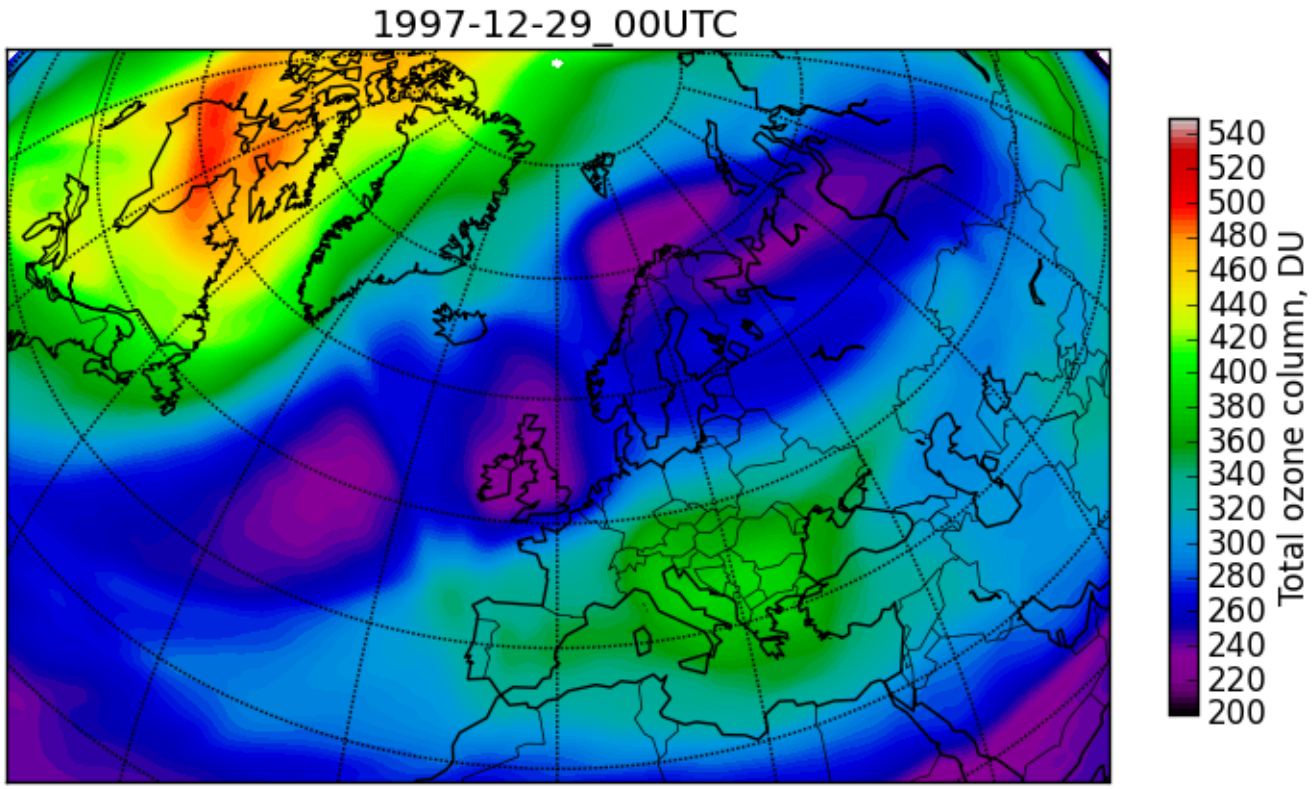


Case I (Dec 1997 – Jan 1998)

OpenIFS simulation, T255, init: 1997-12-25_00

Total ozone column (DU)



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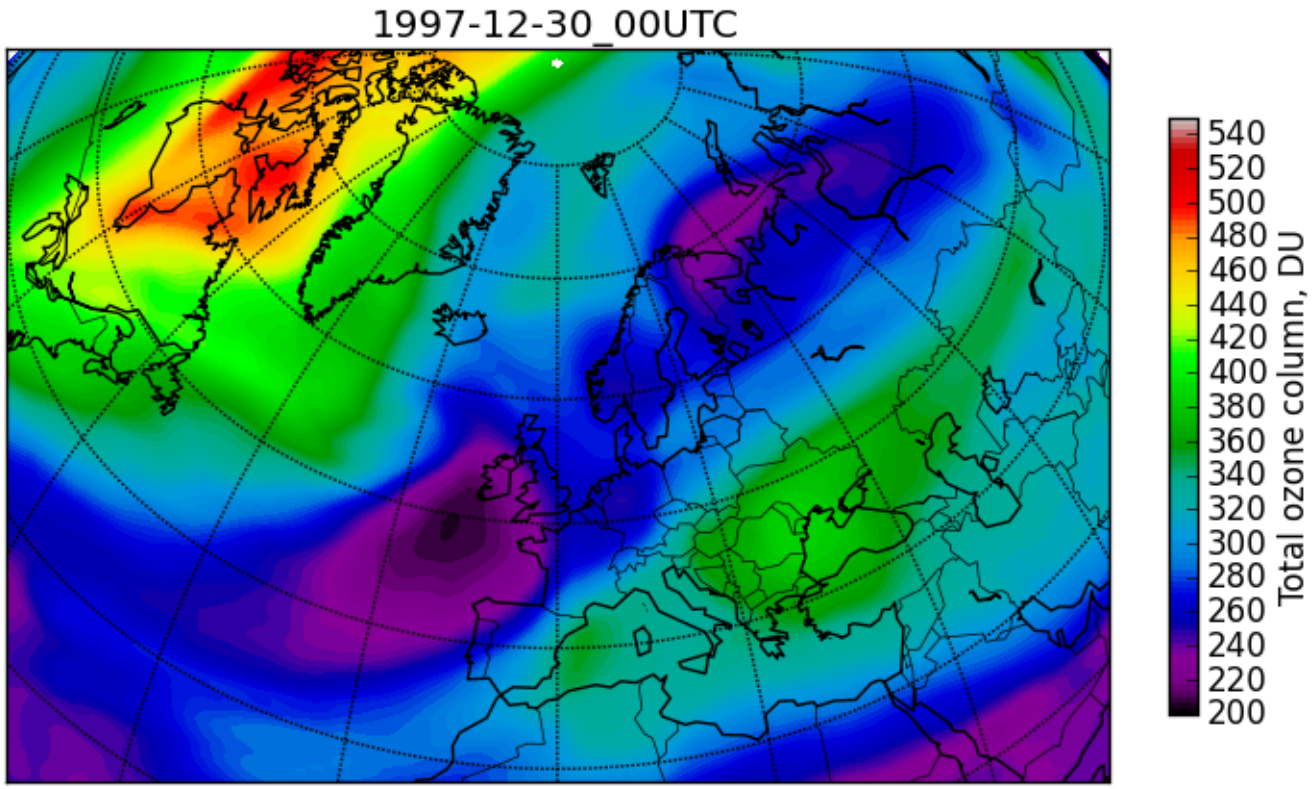
OpenIFS simulation, T255, init: 1997-12-25_00

Total ozone column (DU)



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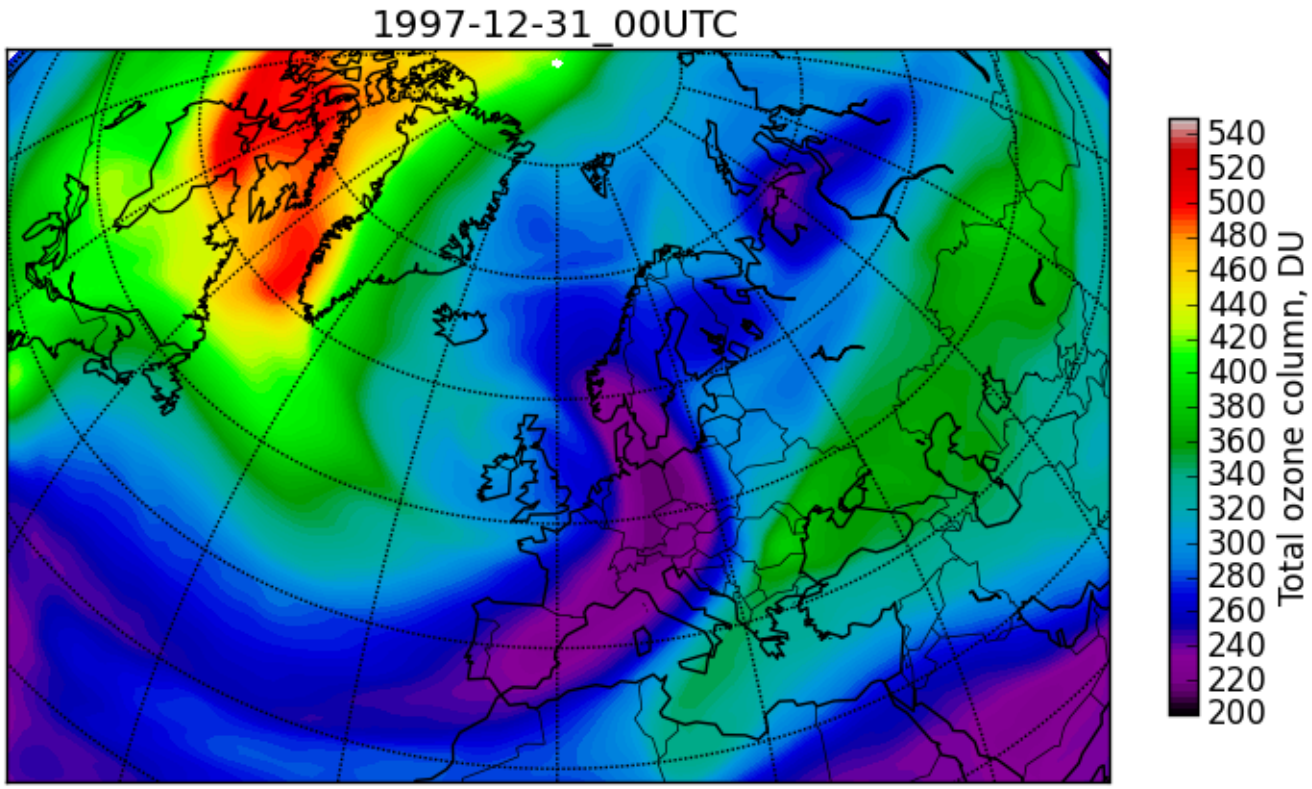

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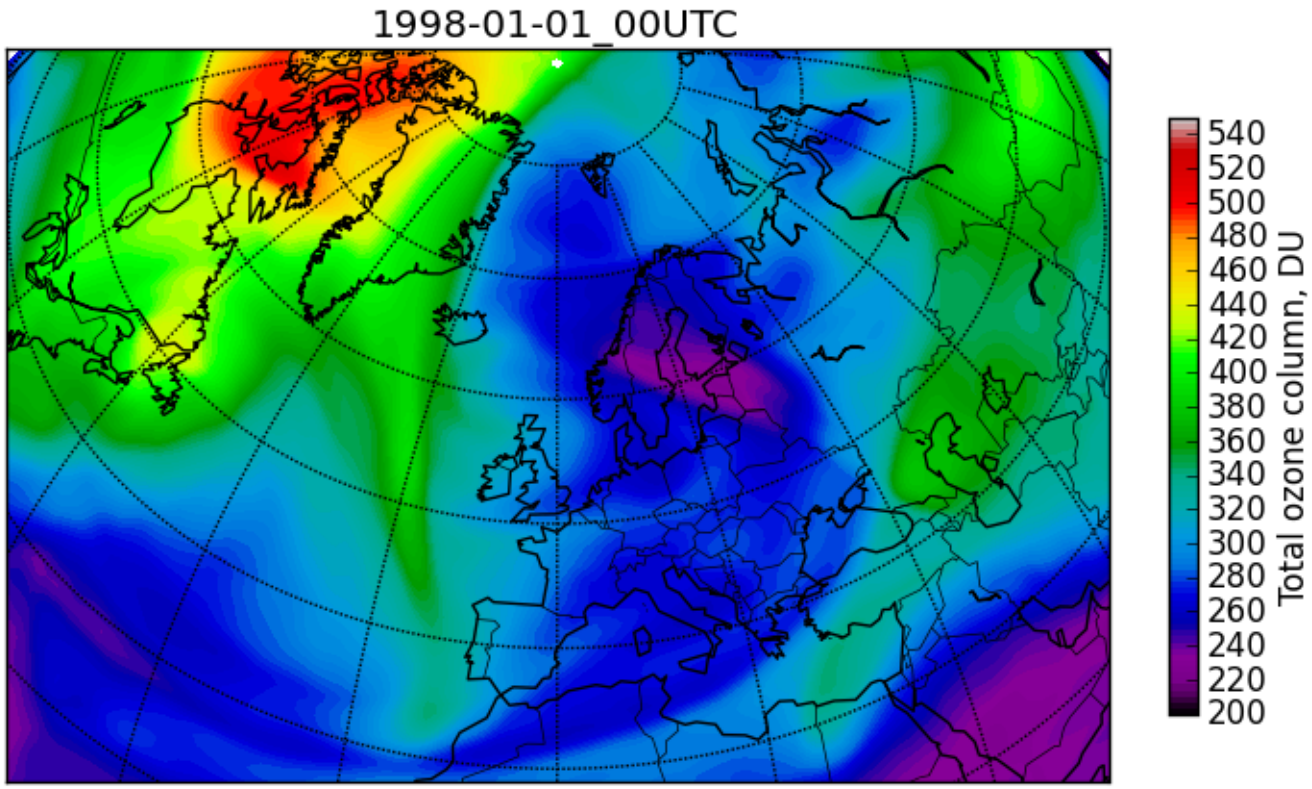

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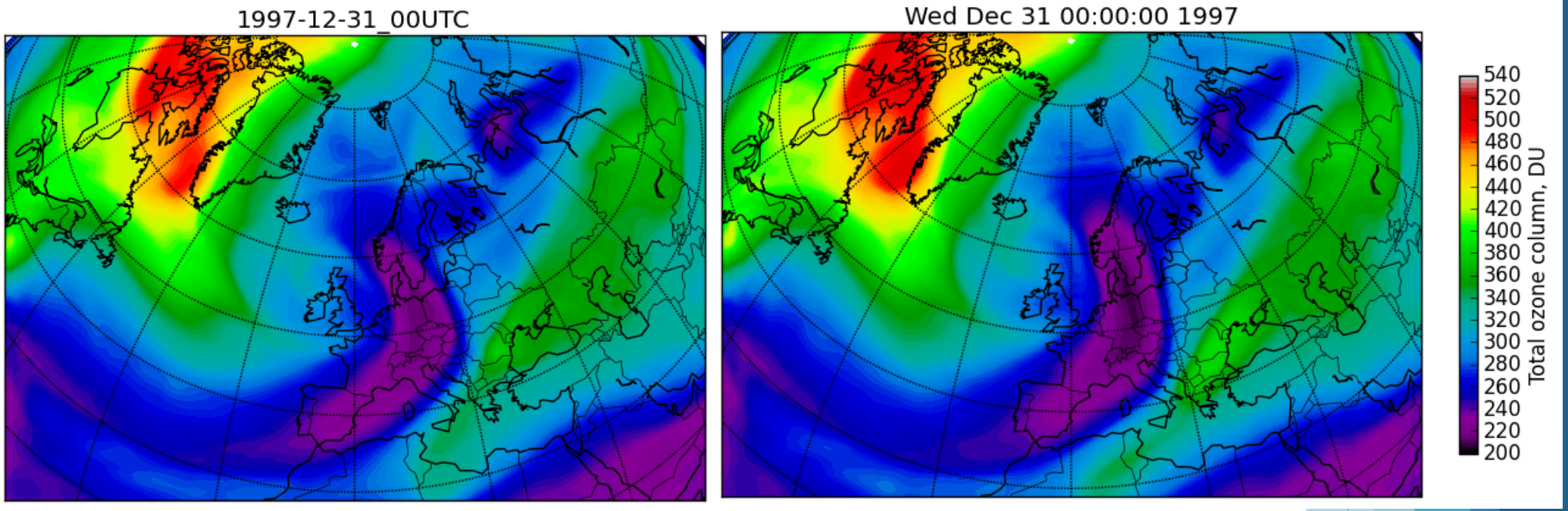
OpenIFS simulation, T255, init: 1997-12-25_00, TOC (DU)

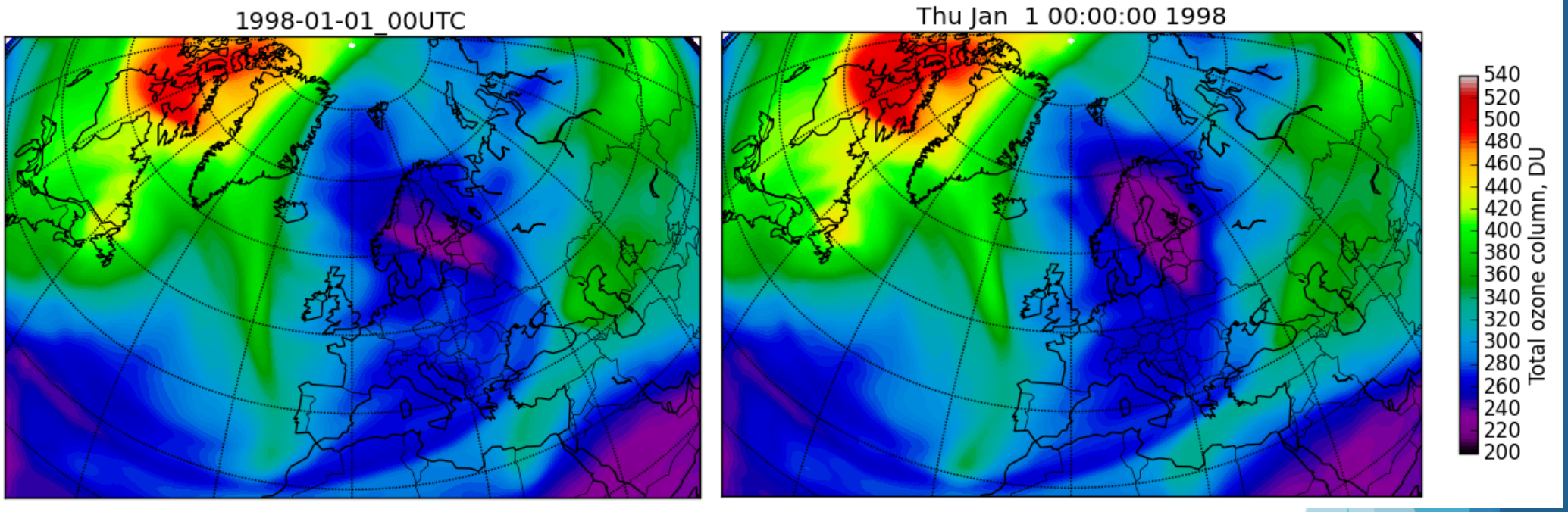


cy38

cy40

Case I (Dec 1997 – Jan 1998)

OpenIFS simulation, T255, init: 1997-12-25_00, TOC (DU)

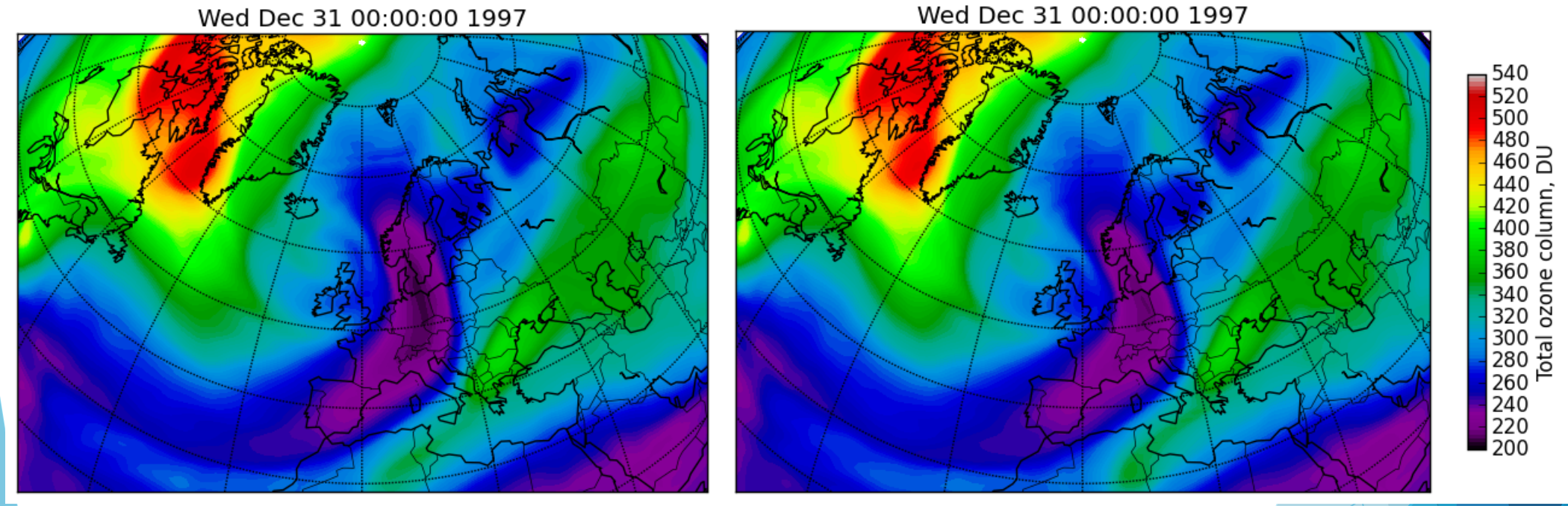


cy38 **cy40**

Case I (Dec 1997 – Jan 1998)

OpenIFS simulation, T255, init: 1997-12-25_00, TOC (DU)

CY40 → ozone in the radiation scheme:



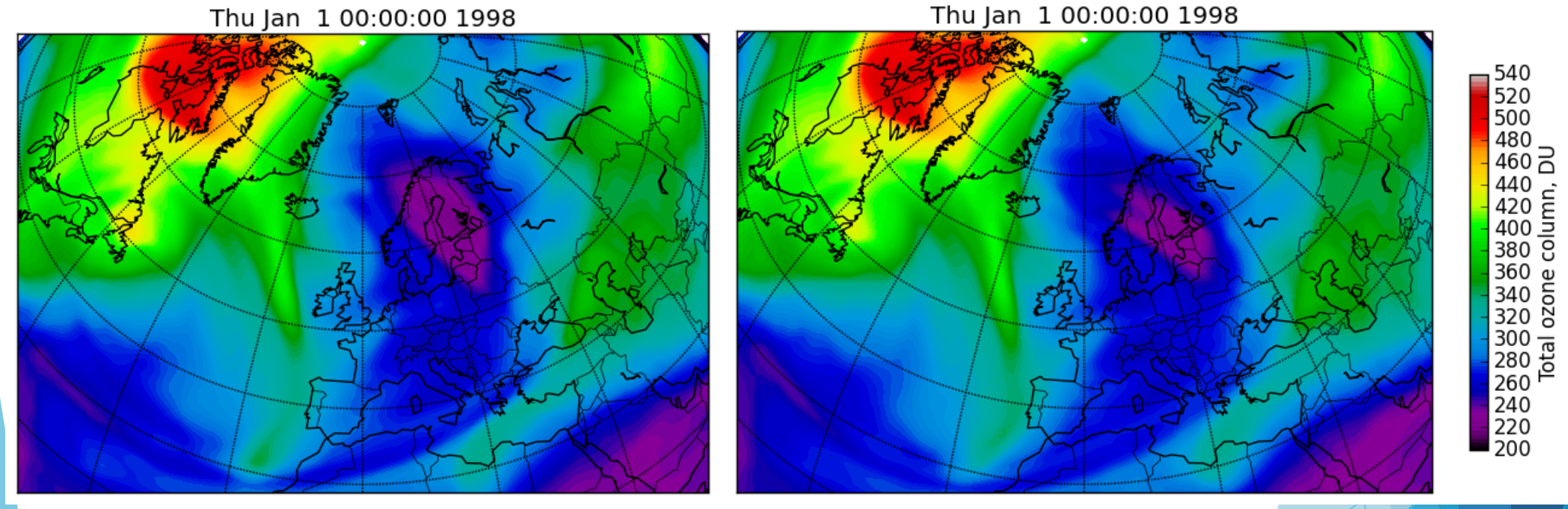
ozone from climatology

prognostic ozone

Case I (Dec 1997 – Jan 1998)

OpenIFS simulation, T255, init: 1997-12-25_00, TOC (DU)

CY40 → ozone in the radiation scheme:

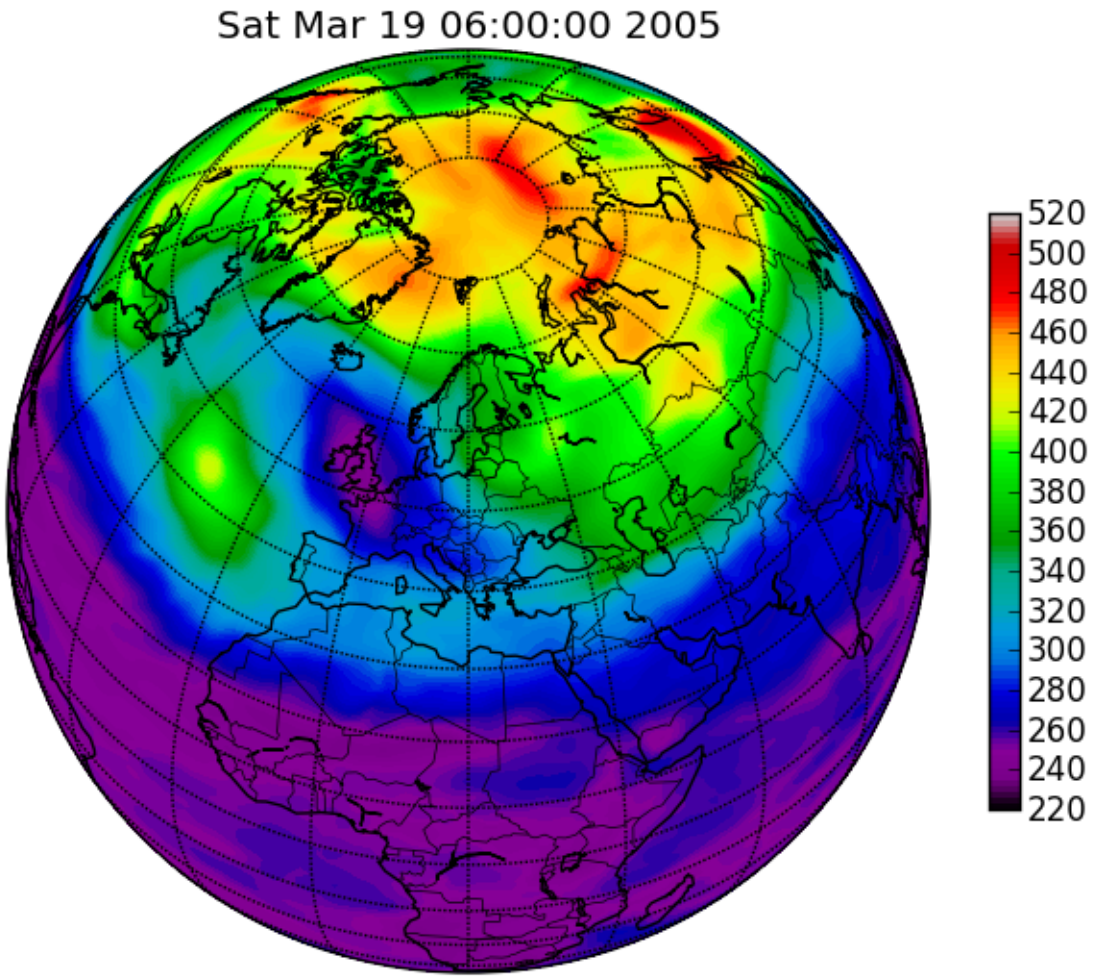


ozone from climatology

prognostic ozone

Local ozone anomalies

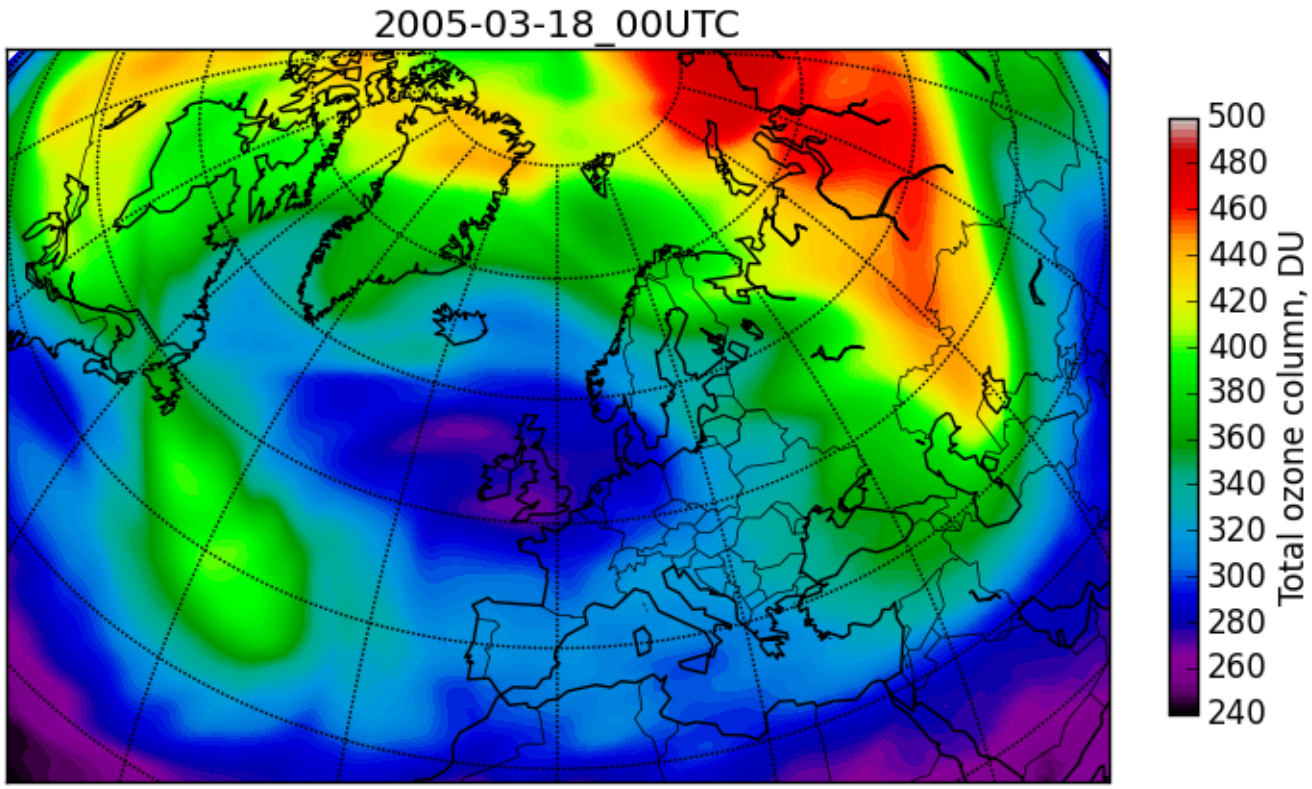
Case II – March 2005



Ozone mini-hole over UK in March 2005

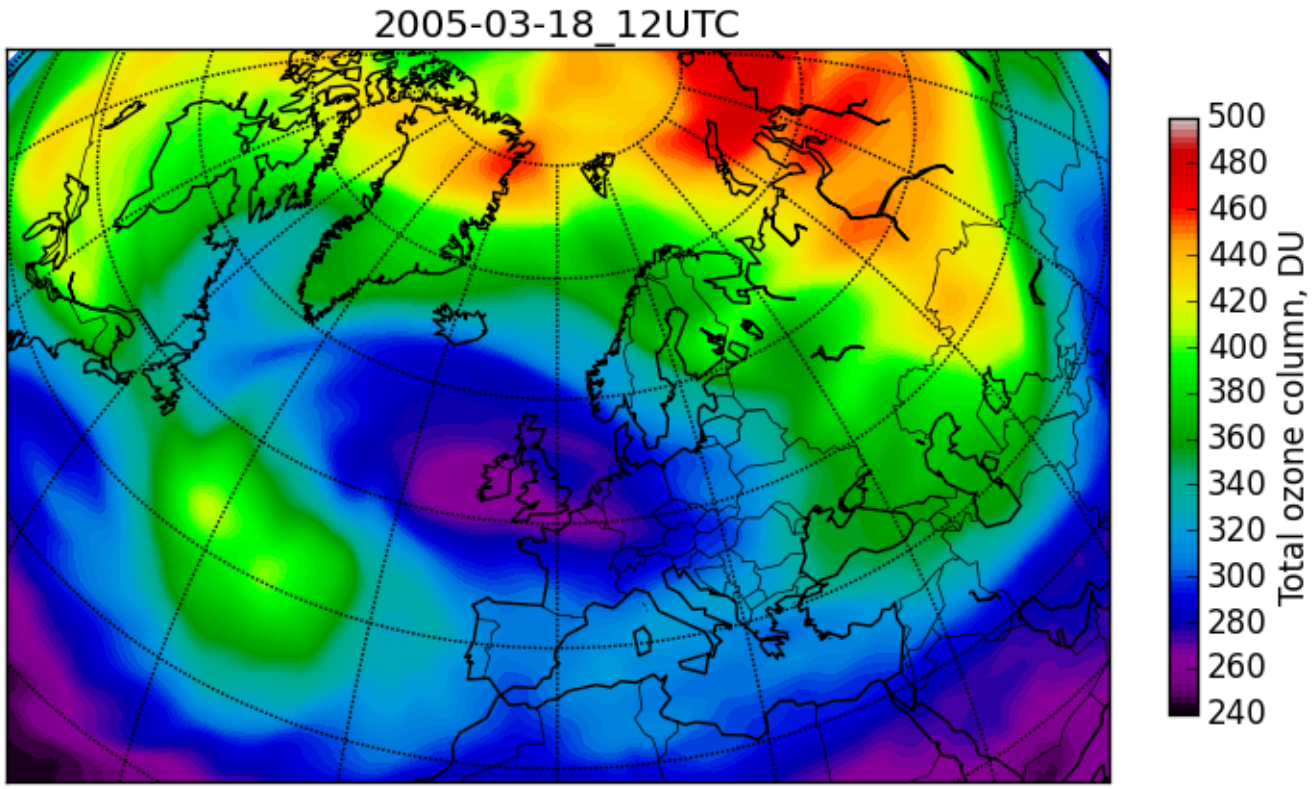
Case II (Mar 2005)

Total ozone column (DU), ERA-Interim



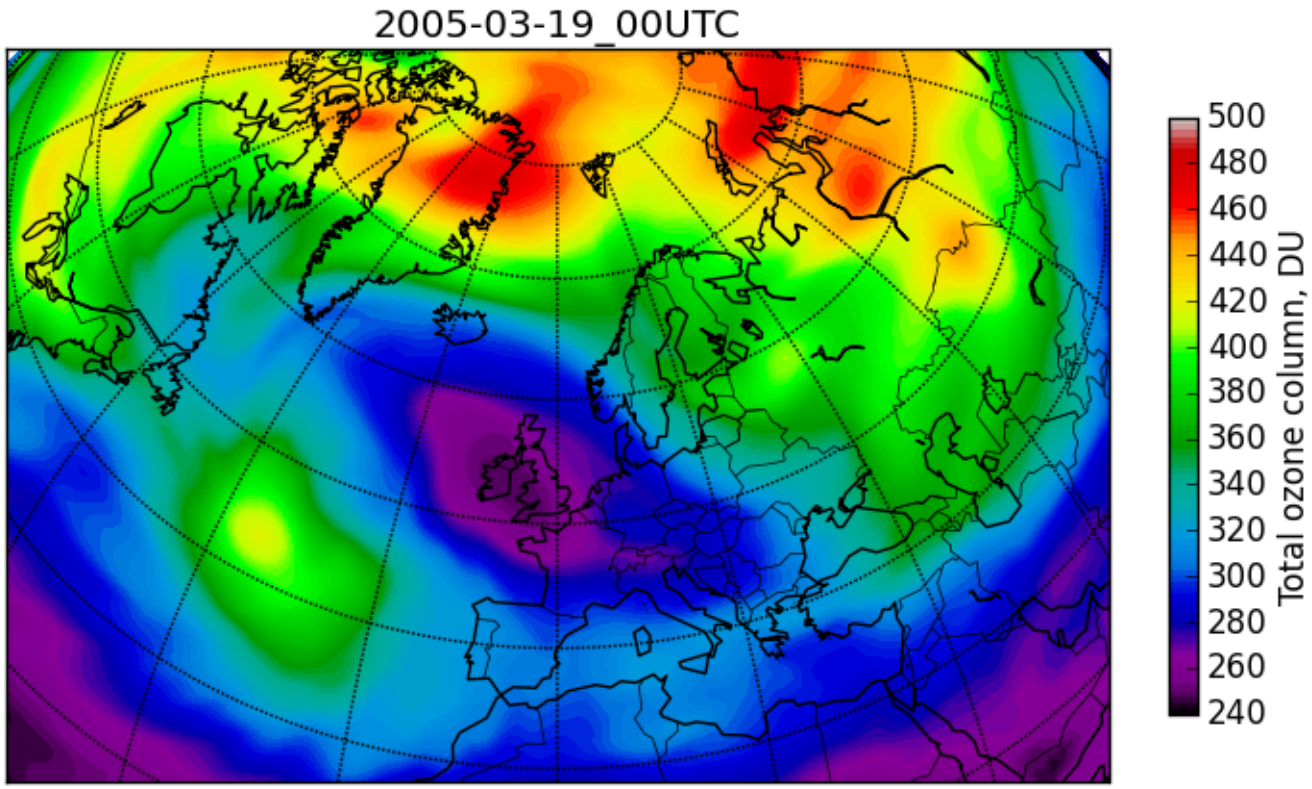
Case II (Mar 2005)

Total ozone column (DU), ERA-Interim



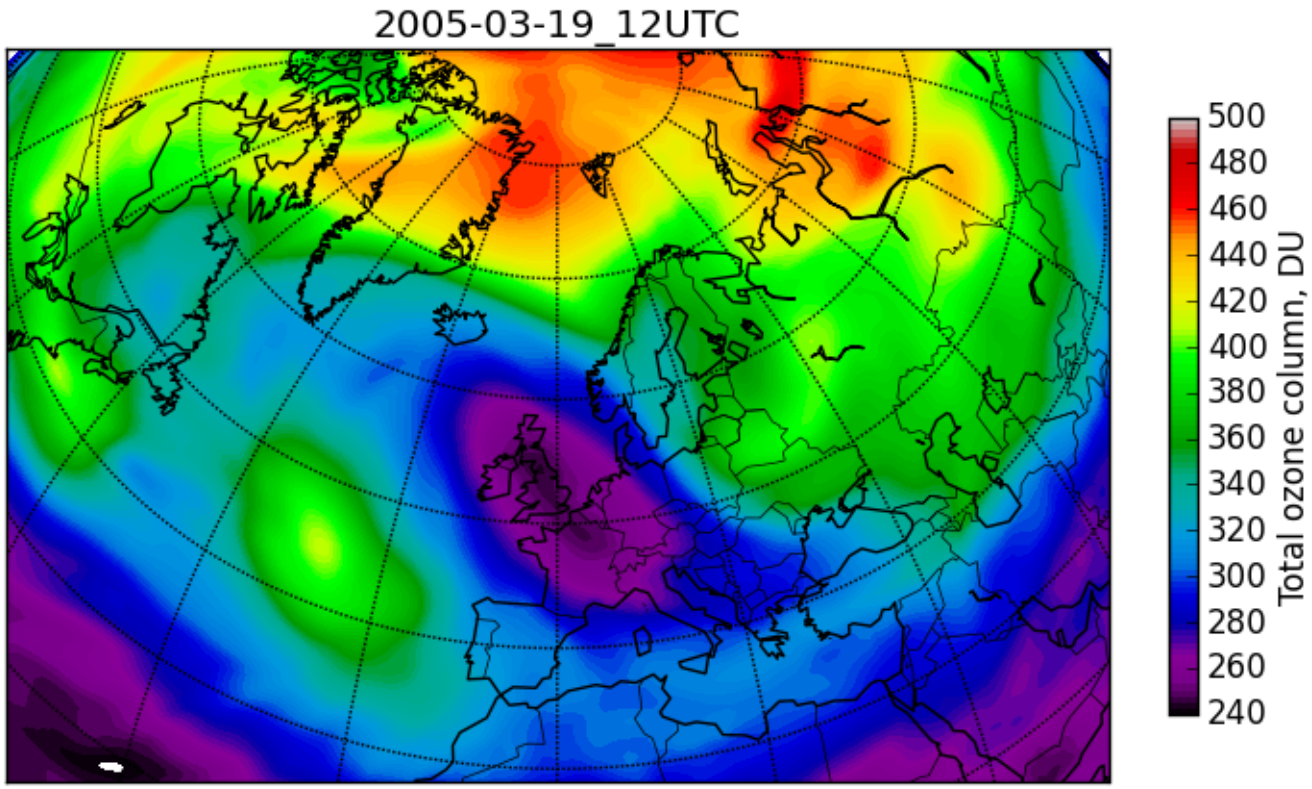
Case II (Mar 2005)

Total ozone column (DU), ERA-Interim



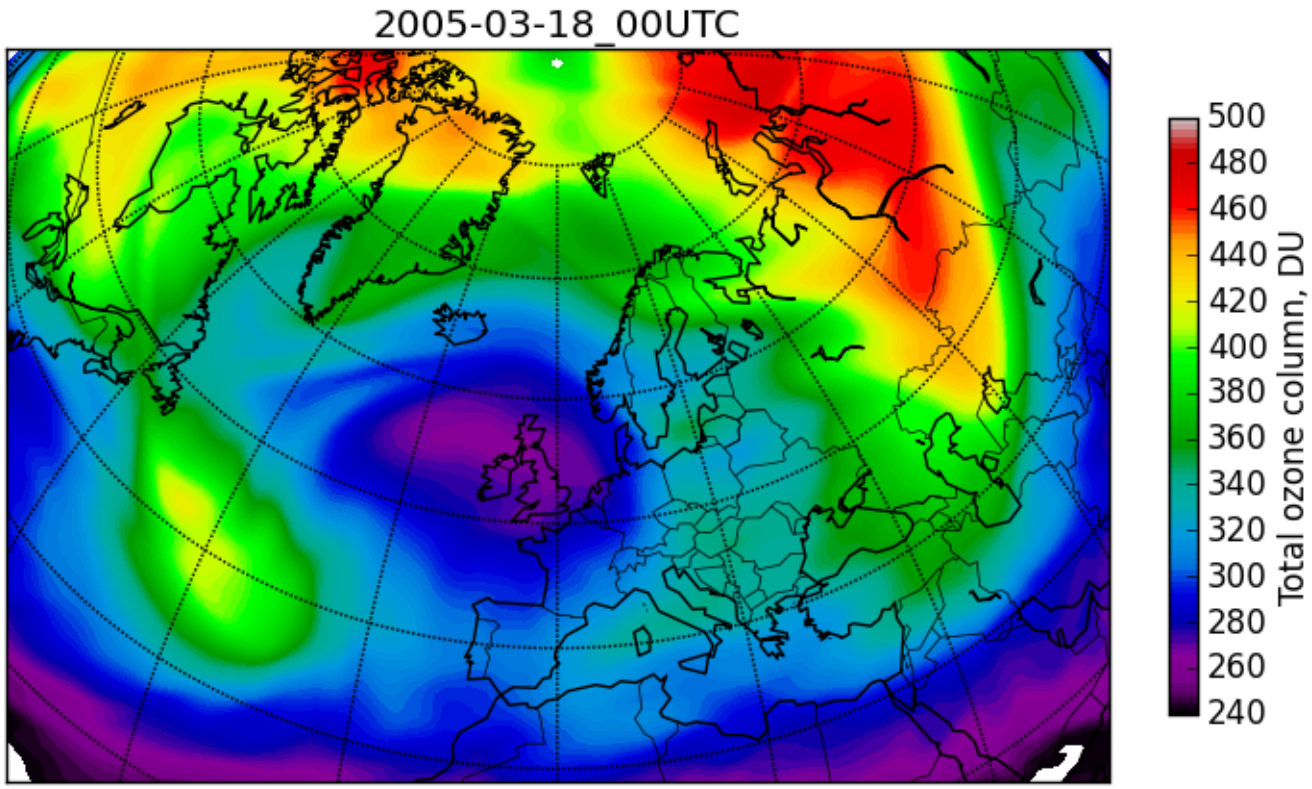
Case II (Mar 2005)

Total ozone column (DU), ERA-Interim



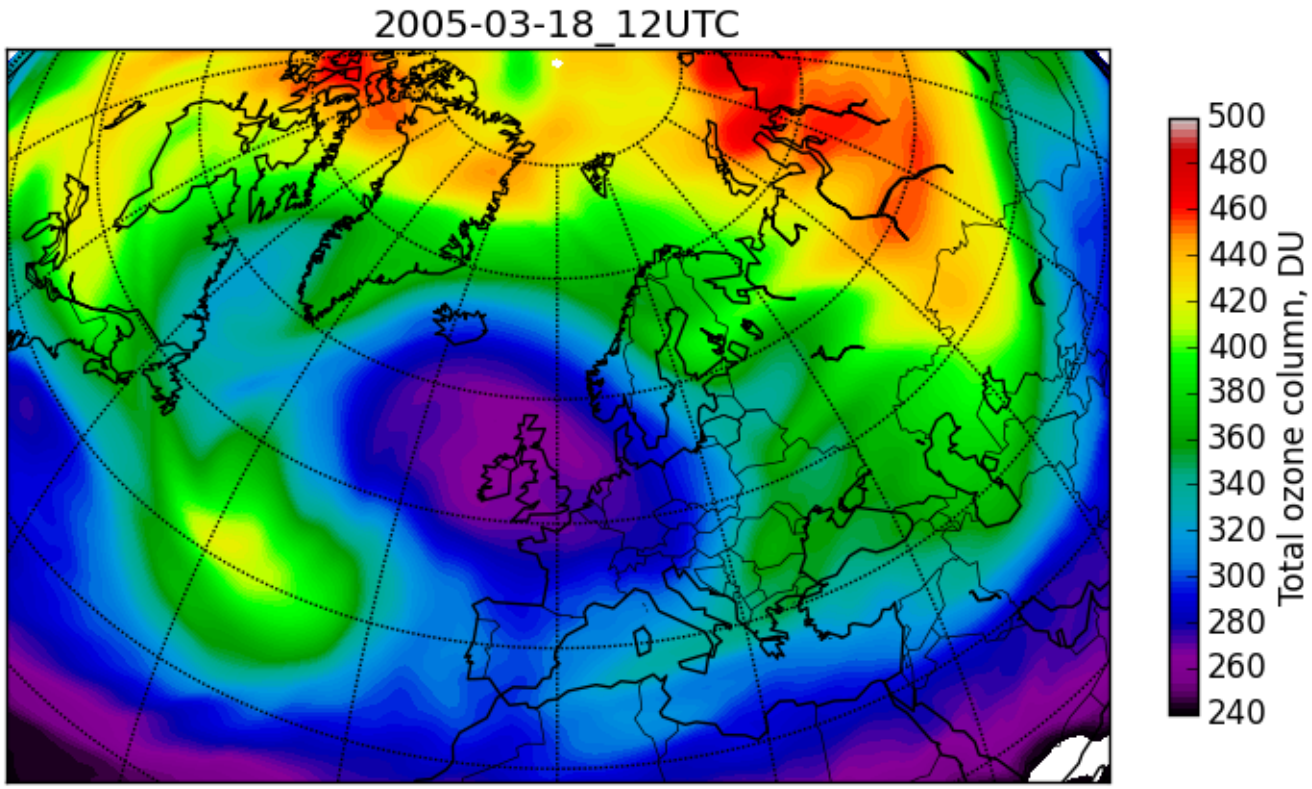
Case II (Mar 2005)

OpenIFS simulation, T255, init: 2005-03-15_00
Total ozone column (DU)



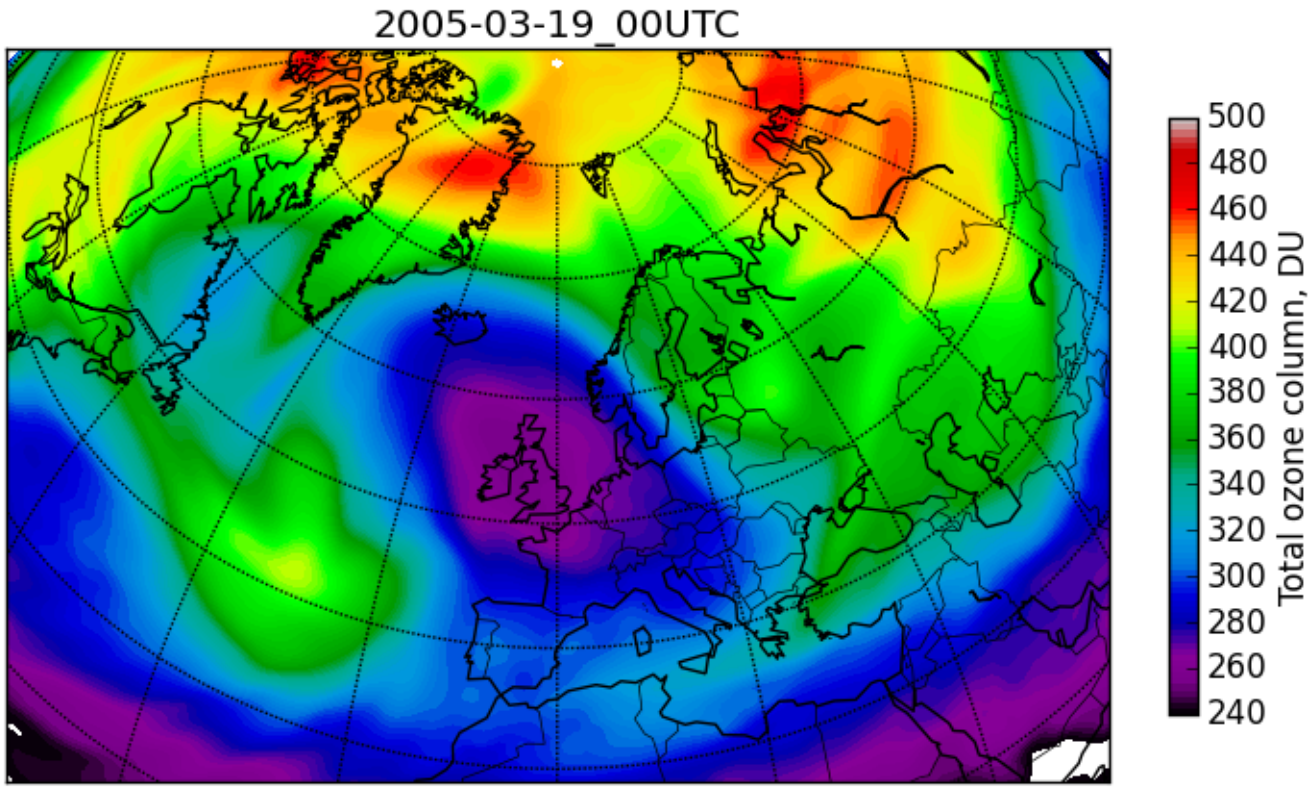
Case II (Mar 2005)

OpenIFS simulation, T255, init: 2005-03-15_00
Total ozone column (DU)



Case II (Mar 2005)

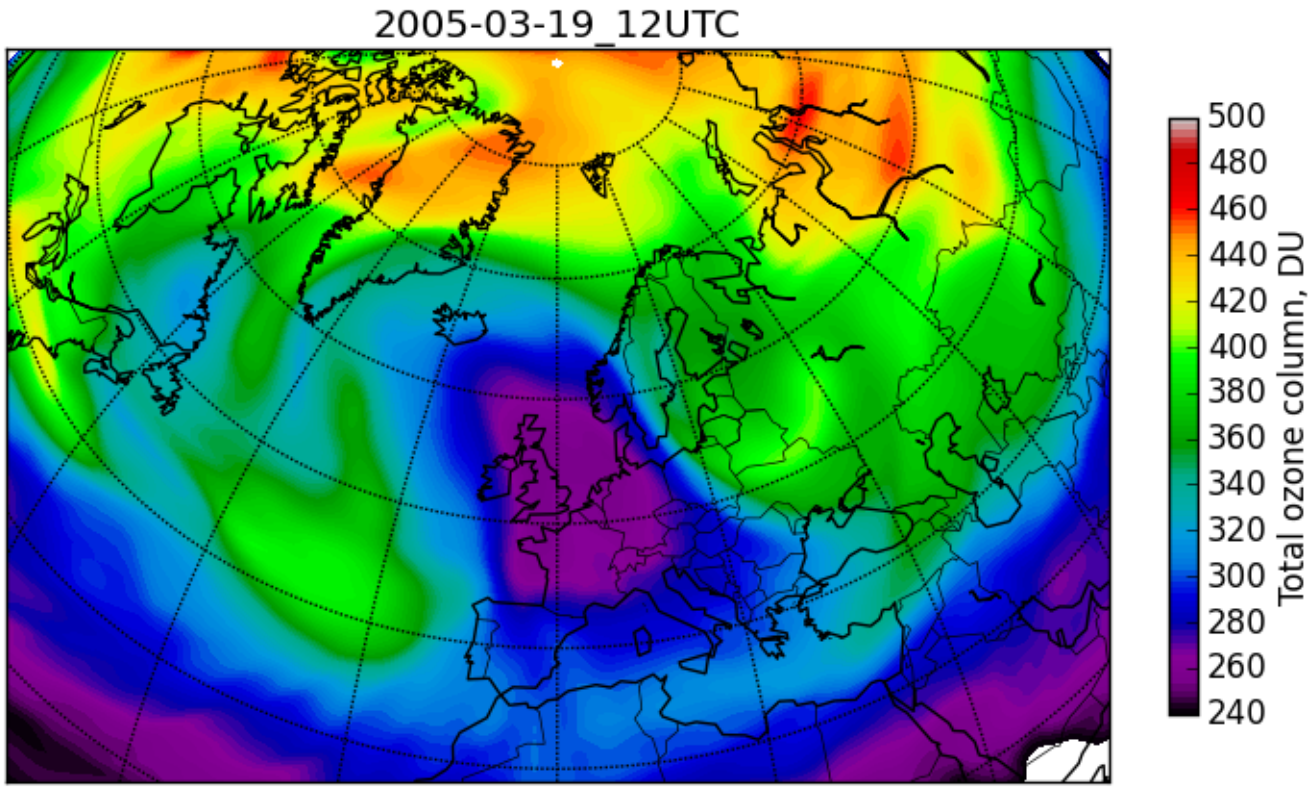
OpenIFS simulation, T255, init: 2005-03-15_00
Total ozone column (DU)



Case II (Mar 2005)

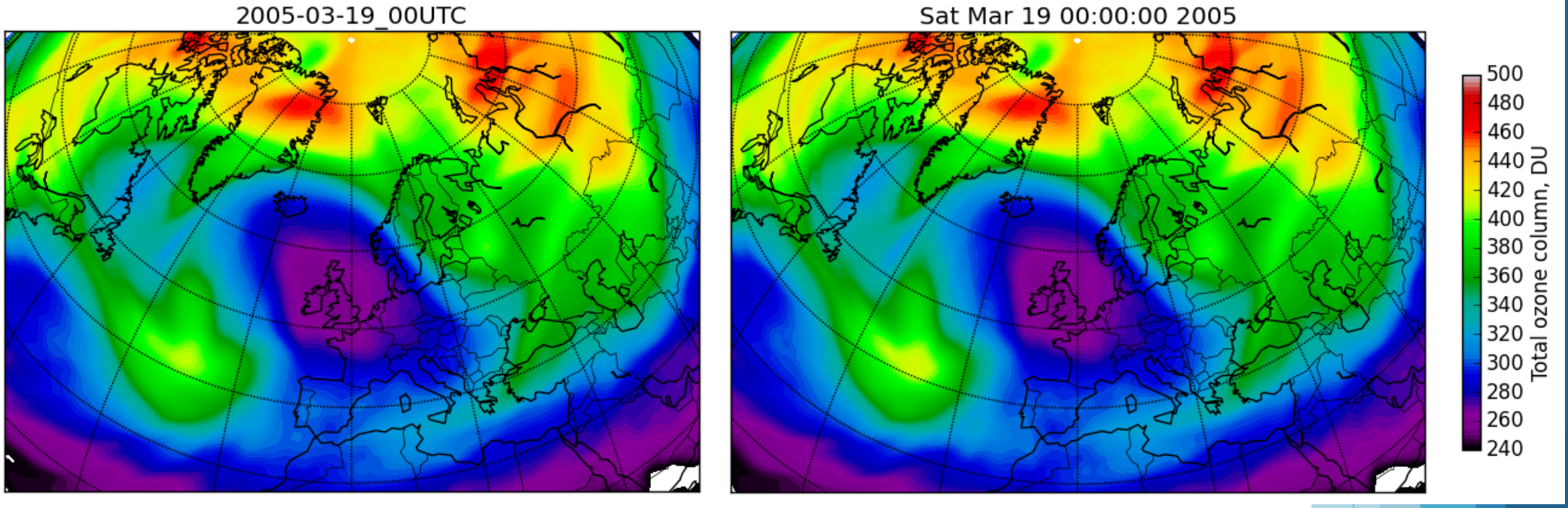
OpenIFS simulation, T255, init: 2005-03-15_00

Total ozone column (DU)



Case II (Mar 2005)

OpenIFS simulation, T255, init: 2005-03-15_00, TOC (DU)

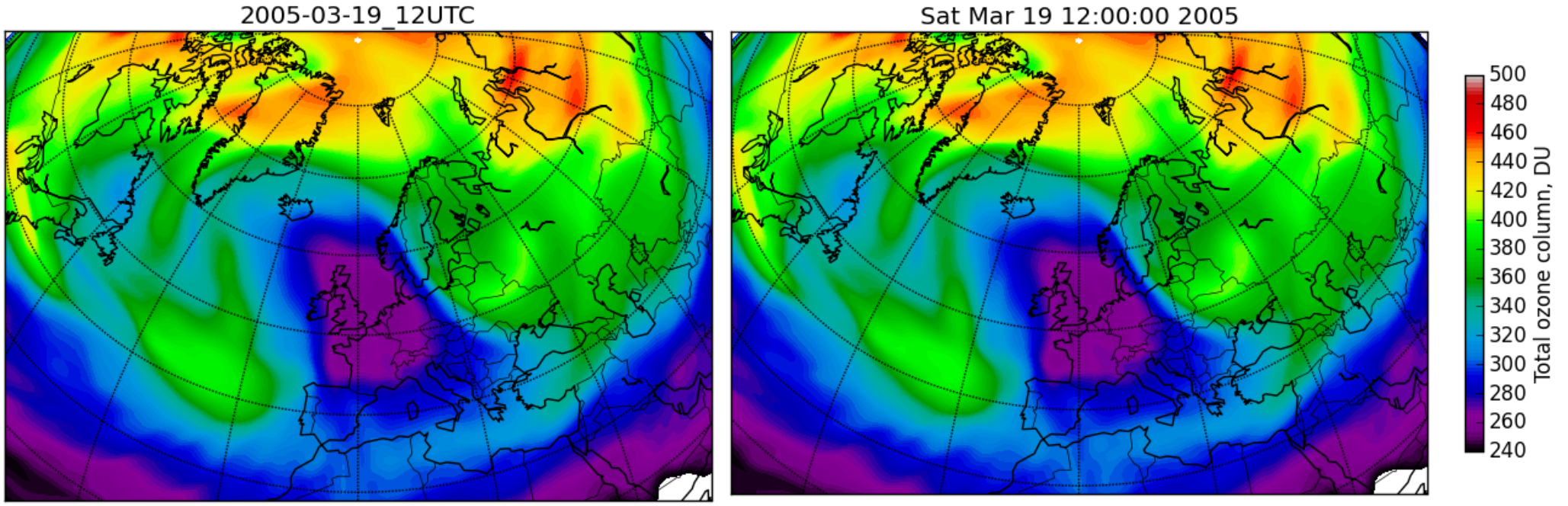


cy38

cy40

Case II (Mar 2005)

OpenIFS simulation, T255, init: 2005-03-15_00, TOC (DU)

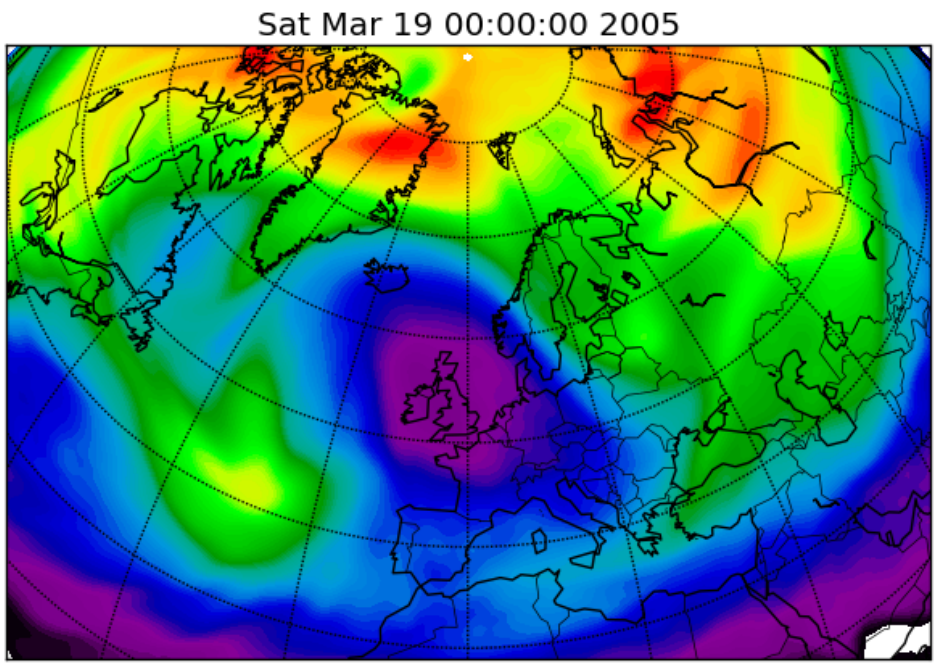


cy38 **cy40**

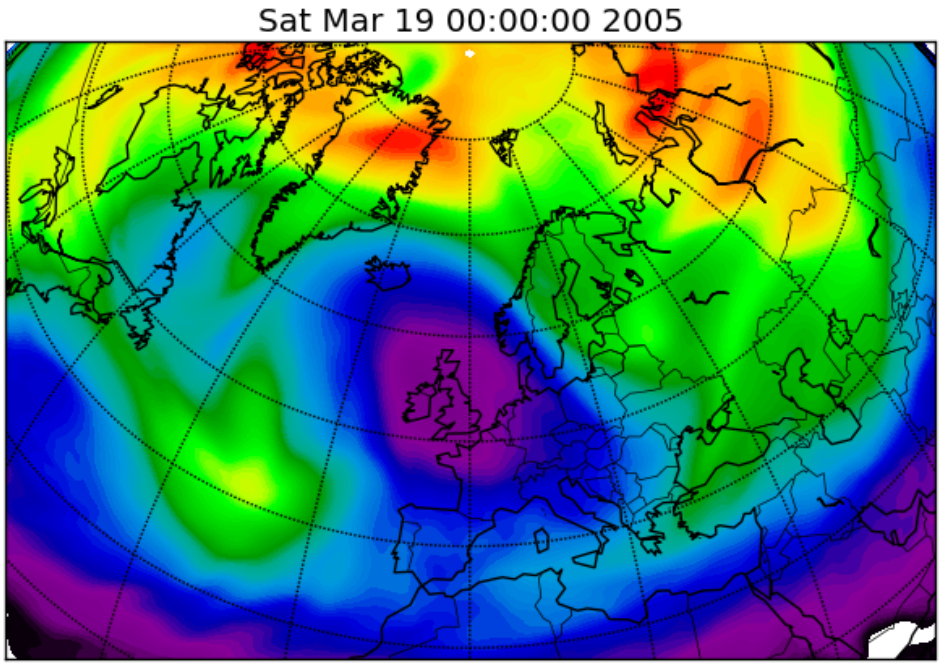
Case II (Mar 2005)

OpenIFS simulation, T255, init: 1997-12-25_00, TOC (DU)

CY40 → ozone in the radiation scheme:



ozone from climatology

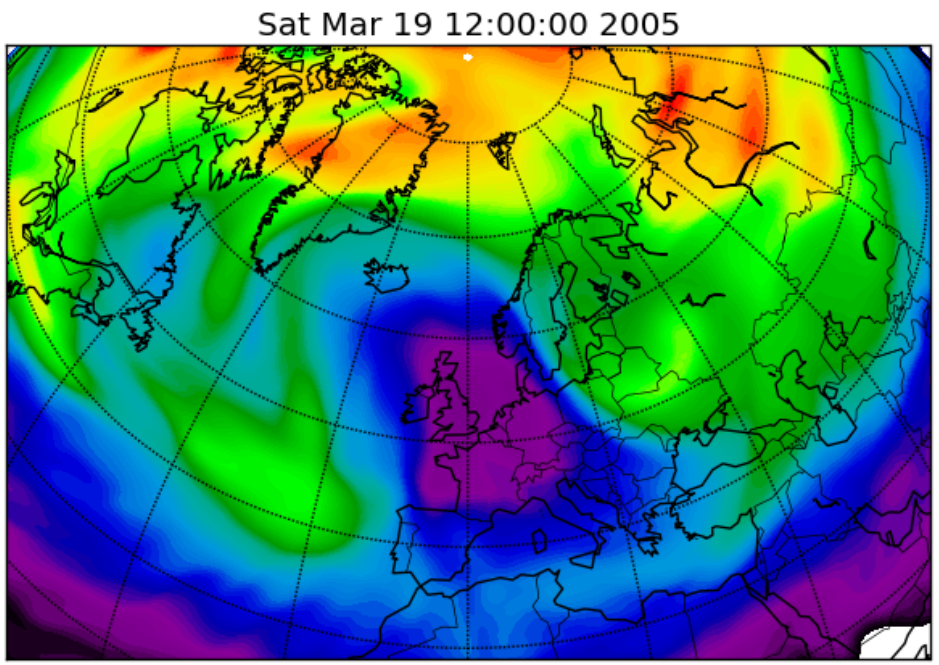


prognostic ozone

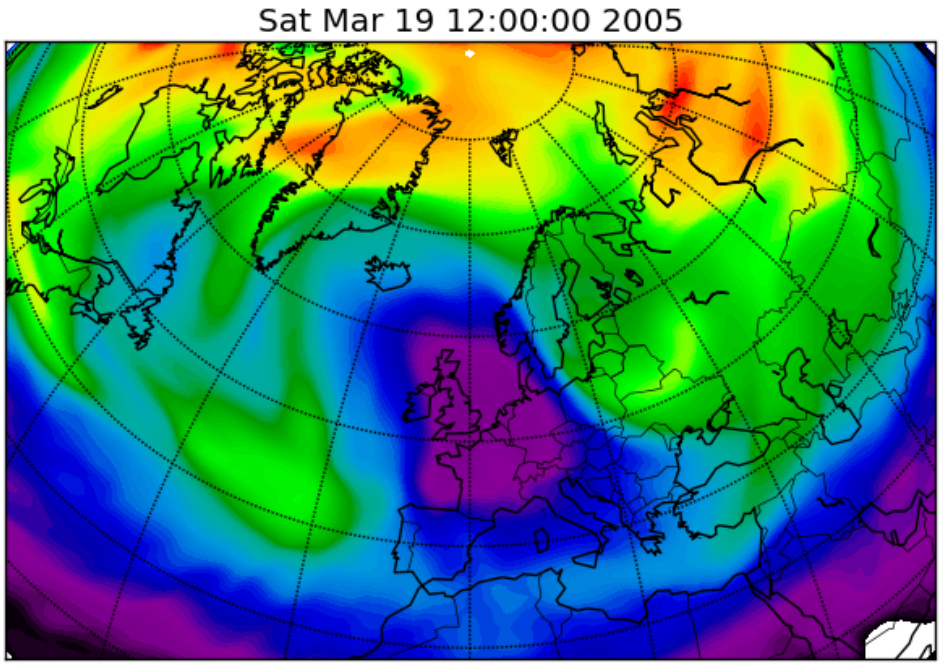
Case II (Mar 2005)

OpenIFS simulation, T255, init: 1997-12-25_00, TOC (DU)

CY40 → ozone in the radiation scheme:



ozone from climatology



prognostic ozone

Thank you for your attention