Global satellite observations of iodine monoxide and the seasonal cycle above Antarctica

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Introduction

General importance of iodine:

- Halogens are involved in ozone destruction cycles.
  (esp. Br in troposphere, Cl in stratosphere) → influence on oxidation capacity
- Iodine shows high O_3 depletion potential ($I + O_3 \rightarrow IO + O_2$)
- IO can lead to enhanced release of other halogens (e.g., via IO + XO).
- High concentrations of IO can lead to the formation of fine particles.

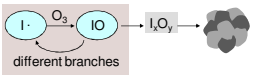


Figure (above): Simple scheme of iodine reactions, involvement of IO and formation of particles.

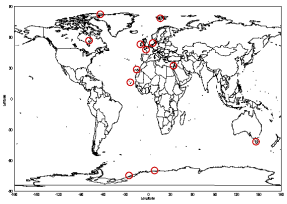


Figure (right): Locations of ground based measurements of atmospheric iodine compounds.

Observations of iodine species:

Iodine species have been observed in several locations (coastal areas, polar regions).

- Compounds: IO, OIO, I_2, organic iodine (e.g. CH_3I, CH_2I_2), and others
- Abundances: for IO typically amounts of a few pptv (range: approx. 0-20 pptv)
- Occurence: rather concentrated in space and time, high values are transitory events
- Sources: supposedly organic precursors; release of atomic iodine after photolysis; in some cases connection to algae population (coastal areas at low tide); directly from sea salt (yet unclear)

SCIAMACHY

SCanning **I**maging **A**bsorption spectro**M**eter for **A**tmospheric **CH**artograph**Y**

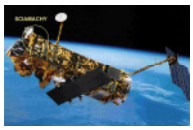


Figure: SCIAMACHY onboard ENVISAT, Monitoring the Changing Earth's Atmosphere, Published by DLR, 2006.
(Photo: ESA, artist's impression)

- UV-Vis-NIR spectrometer onboard Envisat (launched March 2002)
- sun-synchronous orbit at 800 km altitude, descending node
- wavelength range: 214 – 2400 nm (non-continuously)
- geometries: nadir, limb, occultation
- swath width: 960 km
- typical ground pixel: 30 x 60 km²
- equator crossing time: 10:00 a.m.

IO retrieval

$A^2\Pi^{3/2} \leftarrow X^2\Pi^{3/2}$ transition

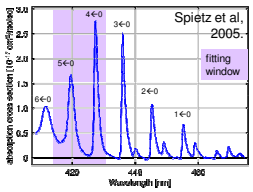


Figure : Absorption spectrum of IO (six of eight lines) and the applied fitting window for the DOAS retrieval.

IO retrieval settings

Method: **D**ifferential **O**ptical **A**bsorption **S**pectroscopy
Fitting window: 416 – 430 nm → 2 absorption bands of IO
Trace gases: NO_2 (223K), O_3 (221K), IO (298K)
Other features: Ring effect, stray light correction, quadratic polynomial

A region in the Pacific (at 40°S, 200°E, +/.10°) is chosen as reference point. All IO columns are differences w.r.t. this location.

Applied SCIAMACHY data:
Spectra from nadir geometry, channel 3 (cluster 14,15), averaged to a ground pixel size of 60 x 120 km².

IO – global map and special regions

Global IO map

IO columns have been retrieved from more than four years of SCIAMACHY data. The detection limit for IO depends on, e.g., albedo and spatial/temporal averaging. For 90% albedo and a ground scene size of 60x120 km², the limit is about $3 \cdot 10^{12}$ molec/cm² for a single measurement.

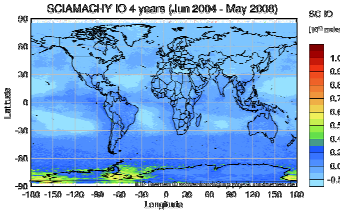
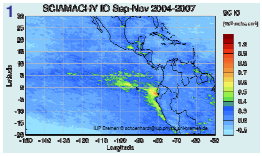


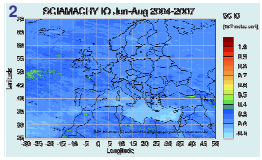
Figure (left): Global map showing the IO slant column averaged over 4 years. Seasonal dependencies are therefore not resolved. The highest values are found in the Antarctic region. Here, the detection of IO benefits from a high ground spectral reflectance and high sensitivity to the ground layers. Some other interesting locations are discussed below.

Interesting regions for IO detection:

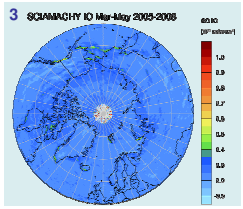
- **Upwelling regions in the tropical oceans** (1)
  → in some periods, enhanced IO is detected in the tropics, west of South America.
  → the origin might be biological productivity, possibly biogenic iodine compounds are released here.
  → IO fits are not as stable here, caution is necessary!



Towards the North, the IO fit shows a tendency for negative values. To avoid this problem, a reference region in the North (30°N, 180°W) is used for plots (2,3) at the moment. This needs to be improved.



- **European coastlines with strong tidal variation** (2)
  → ground based instruments observe IO at low tides. (production by algae after exposure to air)
  → tidal selection criteria were applied to separate satellite observations at low tides.
  → also in the sorted data, no enhanced IO was seen in the respective coastal areas (Mace Head, Roscoff).
  → this result is not unexpected - the satellite pixels are much larger than the source regions, the IO amounts are below detection limit.

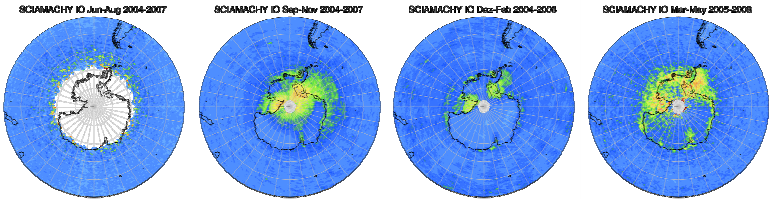


- **North polar region** (3)
  → weak indications of IO along some coastlines in the North appear, but this is still under investigation.
  → no widespread enhanced IO amounts are seen in the Northern Hemisphere, as compared to the Antarctic.
  → no maximum like BrO at North Pole and Hudson Bay.

IO in Antarctica

IO seasonal variation on the Southern Hemisphere

- Seasonal variation of IO over Antarctica: maxima in Antarctic spring and autumn, lower but still positive values in summer, no high IO amounts seen in winter time (in the area accessible to satellite measurements)
- Regions of enhanced IO: sea ice covered regions, shelf ice areas, coast lines, as well as (surprisingly) parts of the continent



Figures (above): Southern hemispheric maps showing the IO slant column retrieved from SCIAMACHY nadir observations. In each case, the IO data is averaged over 4 years: for Antarctic winter, spring, summer, and autumn (from left to right).

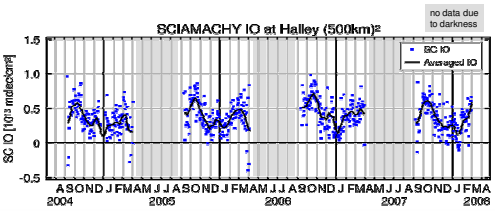
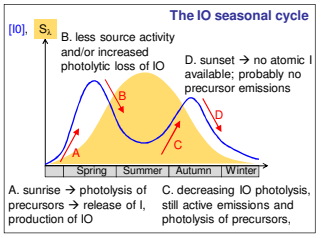


Figure (right): IO time series at Halley Station (75.5°S, 26.5°W), daily IO values in blue, a weekly average in black. IO has also been detected by ground based measurements there. In each year, the pattern repeats with a maximum in spring (October), lower values in summer and a second rise in autumn.

Influencing factors for the seasonal cycle:

1. Precursor amounts (e.g. organohalogens from algae)
2. Sunlight for photolytic release of atomic iodine (actinic flux S_λ).

The need of sunlight favours IO occurrence from spring to autumn. Precursor concentrations are not well known, emissions from ice algae may contribute to a seasonal cycle (e.g., biological activity is more concentrated to the surfaces in spring and autumn).



High IO values on the Antarctic continent

- Sources inland: unknown up to now
- Direct transport of IO: improbable (short IO lifetime)
- Possible process: a combination of transport and IO recycling involving aerosol and snow surfaces

Comparison of IO with BrO values

Similarities: Maxima of IO and BrO occur in the same region and same time of year (Antarctic spring).
Differences: The exact spatial patterns are different.
No second maximum is seen in autumn for BrO.
No strong maximum appears in Arctic spring for IO (as there is for BrO).

Conclusions

- IO slant columns with amounts up to $8 \cdot 10^{12}$ molec/cm² in the monthly average have been observed by SCIAMACHY. The largest IO columns are detected close to Antarctica.
- The observed seasonal cycle repeats in each of the four analysed years with maxima in spring and autumn, probably caused by a combination of precursor concentration and actinic radiation.
- Surprisingly high values over the Antarctic continent are not well understood, but may be effected by recycling processes on aerosol/snow surfaces and by transport. Further studies are needed.
- Localised emissions at European coasts in the marine boundary layer remain undetected so far.
- Over the Arctic region much lower IO values are observed than over the Antarctic. These weak indications for IO detections in the Arctic need to be further investigated.

Acknowledgements

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see also: www.iup.uni-bremen.de/doas