**Project no. 265863**

# ACCESS

## Arctic Climate Change, Economy and Society

Instrument: Collaborative Project
Thematic Priority: Ocean.2010-1 “Quantification of climate change impacts on economic sectors in the Arctic”

# D1.71 – Radiative forcing estimates for perturbation in the Arctic of short lived climate compounds

Due date of deliverable: **28/02/2014**
Actual submission date: **21/03/2014**

Start date of project: **March 1st, 2011** Duration: **48 months**

Organisation name of lead contractor for this deliverable: **CICERO**

| | | |
|---|---|---|
| **Project co-funded by the European Commission within the Seventh Framework Programme (2007-2013)** | | |
| **Dissemination Level** | | |
| **PU** | Public | |
| **PP** | Restricted to other programme participants (including the Commission Services) | |
| **RE** | Restricted to a group specified by the consortium (including the Commission Services) | |
| **CO** | Confidential, only for members of the consortium (including the Commission Services) | X |

# Contents

# 1. Predicted impacts on radiative forcing from future increases in Arctic shipping

In WP1 Deliverables D1.71 and D1.72 in ACCESS studies were made to quantify impacts on climate and air pollution levels of local Arctic emission sources both for the current and future. These are performed in synergy and addition to chemistry-climate work in WP2 and WP4 which is focusing on smaller scales using campaign data. The OsloCTM2 model and a Radiative Forcing (RF) model were used to study the evolution of chemical constituents causing impacts in the Arctic. The composition changes of air pollutants calculated by the CTM were presented in Deliverable D1.71. This report focuses RF results and impacts on climate

Specifically for ACCESS, Dalsøren et al. 2013 calculates impacts of future global and Arctic shipping with a particular focus on different scenarios for soot emissions. Corbett et al. (2010) provides gridded inventories for current (2004) and future (2030, 2050) ship emissions of greenhouse gases and gas and particulate pollutants in the Arctic. That study presents several options for emission totals and diversion routes through the Arctic in 2030. In this study we compare their highest and lowest 2030 estimates to get an impression of the range of possible future effects due to emissions of NOx, SOx, CO, NMVOCs, BC and OC (Table 1). The two datasets for ship emissions are used to characterize the potential impact from shipping and the degree to which shipping controls may mitigate impacts: A high (HIGH) scenario and a low scenario with Maximum Feasible Reduction (MFR) of black carbon in the Arctic. In the high growth scenario (HIGH) there is a large increase in ship traffic within the Arctic. In addition 2 % of the yearly global traffic diverts to Arctic through-routes during late summer. Global shipping growth outside the Arctic is + 3.3% per year. In the Maximum Feasible Reduction (MFR) scenario a business as usual scenario is followed but maximum feasible reduction is applied on Arctic BC emissions (also affecting OC). In this scenario, 1 % of the global traffic (the business as usual scenario from Corbett et al. 2010a) diverts to Arctic through-routes. Global shipping growth outside the Arctic is + 2.1 % per year. In MFR, BC emissions in the Arctic are reduced with 70 % representing a combination technology performance and/or reasonable advances in single-technology performance. Counteracting the traffic growth in both scenarios is a phase in of existing regulations, resulting in reduced emission factors for some components. The emission scenarios are described in detail in Corbett et al. (2010).

| | **$NO_x$** | **$SO_2$** | **BC** | **OC** |
|---|---|---|---|---|
| **2004** | **196** | **136** | **0.88** | **2.70** |
| **2030 HIGH** | **739** | **130** | **4.50** | **5.10** |
| Arctic fleet | 329 | 58 | 2.00 | 2.30 |
| Diversion fleet | 410 | 72 | 2.50 | 2.80 |
| **2030 MFR** | **384** | **68** | **0.76** | **0.84** |
| Arctic fleet | 244 | 43 | 0.46 | 0.51 |
| Diversion fleet | 140 | 25 | 0.30 | 0.33 |

**Table 1:** Ship emissions north of 60° N in 2004 and 2030 (Kton/year) from Corbett et al. (2010). There is seasonal variation in the emissions from the Arctic fleet. The diversion fleet operates in the period August-October.

Both scenarios result in increased atmospheric concentrations of pollutants both globally and in the Arctic. Exceptions are black carbon in the MFR scenario, and sulfur species and organic aerosols since a planned phase-in of IMO regulations reducing fuel sulfur content is taken into account. The net climate impact of the SLCFs might be a warming or a cooling dependent on emission distribution and regional atmospheric conditions. The current net impact of SLCFs from shipping both globally and in the Arctic is a cooling. The study predicts that shipping will contribute to Arctic and global warming from 2004-2030. This is mainly due to reduced cooling impact of sulfate aerosols and clouds as sulfur emissions from ships are reduced.

Very large seasonal variations (up to a factor of 10) are found for Arctic RF (Figure 1). Despite maximum in shipping emissions in summer and early autumn, maximum impact is predicted to be in spring-early summer coinciding with the melting season, making it essential to consider how shipping may accelerate future sea ice and snow cover melt in the region. The total RF is more than a factor 2 larger from May to July compared to the yearly average.

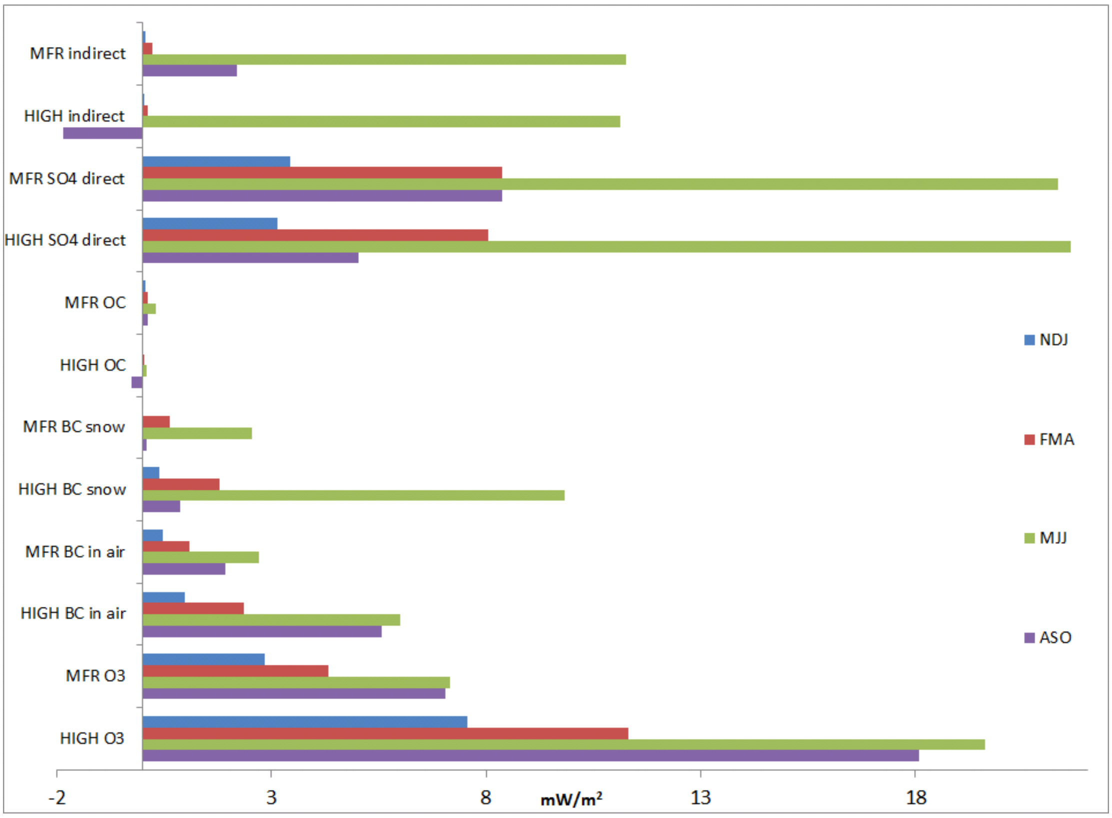

**Figure 1 :** RF 2004-2030 (mW/m$^2$) for short lived climate forcers in the Arctic (60-90°N) for different seasons for the scenarios HIGH and MFR.

We find that phasing in of existing IMO regulations on sulfur are efficient in reducing particle pollution both globally and in the Arctic. The tradeoff is that it leads to a warming. Though black carbon emissions from shipping are small, measures are favored by both reductions in air pollution and a cooling effect. The study finds an important contribution from black carbon in the Arctic in 2030, especially black carbon on snow and ice which efficiently absorb solar radiation warming the surface. The climate impact of black carbon in the Arctic is approximately 60 % lower in the Maximum Feasible Reduction scenario. The effect on ozone ($O_3$) in the Arctic is rather large and the compensating $NO_x$ induced methane cooling is small in the Arctic. In the Arctic, regulations of $NO_x$ could therefore also be favorable both for air quality and climate but this needs to be confirmed by further studies. Such studies should quantify the effect of small-scale processes in the ship plumes possibly reducing the NOx lifetime and associated impacts on the greenhouse gases ozone and methane. Most plume studies so far focused on lower latitudes.

# 2. Radiative forcing and temperature responses to future Arctic transit shipping versus traditional Suez route

The melting of Arctic sea ice may open new shipping routes between Europe and Asia. In a study partly funded by ACCESS (Fuglestvedt et al. in prep 2014) we calculate the climate impact of a shift in shipping traffic from lower latitudes to the Arctic. The Arctic route is shorter relative to the traditional Suez route and could result in significant fuel saving and reductions in $CO_2$ emissions. In addition to $CO_2$, ships emit a number of gases and aerosols with both warming and cooling effects operating on a broad range of time scales. The climate impact of these components depends strongly on location and timing of emissions. Thus, the net climate effect of changes in emissions is not obvious.

We use Arctic shipping emission inventories (Peters et al. 2011) for 2030 and 2050 with a gradual increase in container traffic on a new Arctic route from Europe (Rotterdam) to Asia (Yokohama). The  Arctic transits occur in the period July-November when it is feasible and economically profitable to use the northern route (Peters et al. 2013). The advantage of the northern route compared to the traditional Suez route is shorter (43%) distance and travel time resulting in less fuel consumption and emissions for the *same volume of transported cargo*. This is, however, somewhat compensated by increased fuel consumption per km to break through ice, especially in 2030. Applying the optimal Arctic route reduces the travel time by 37% in 2030 and 43% in 2050, while the fuel consumption is reduced by 29% and 37%. The total whole-year fuel consumption from shipping between Rotterdam and Yokohama is reduced by 10% in 2030 and 16% in 2050. Similar factors apply for relative reductions in emissions to air of chemical constituents ($CO_2$, NOx, SOx, NMVOCs, CO, black carbon (BC), and organic aerosols (OA)) as we assume identical emission factors along the two routes.

The different atmospheric conditions and sensitivity to emissions at high and low latitudes will determine the resulting climate impact of short lived climate forcers (SLCFs). The impacts of $CO_2$ and other long-lived greenhouse gases do not depend on emission location. Figure 2 shows the calculated global annual RF, by component, and total non-$CO_2$ and $CO_2$ RF, for 2030 and 2050. Shifting parts of the shipping from Suez to the Arctic route - i.e. reducing emission at lower latitudes and introducing new emissions in the Arctic - gives positive net RFs from changes in non-$CO_2$ components for 2030 and 2050, respectively. The total non-

$CO_2$ RF values are dominated by the direct and cloud altering aerosol effects of sulfate, effects of BC as well as changes in ozone and methane. $CO_2$, however, has a response time of centuries, which means that the atmospheric levels are determined by emission history. Thus assumptions about emission pathway are needed to quantify its total climate impact. We have assumed linear trends from zero emission in 2025 up to 2030 levels and further to 2050. The calculated RF from $CO_2$ in 2030 and 2050 is small compared to the SLCFs, but this gas has larger effects on longer timescales (see below). Direct emissions of $CH_4$ and $N_2O$ are small and the resulting RFs are found to be negligible.

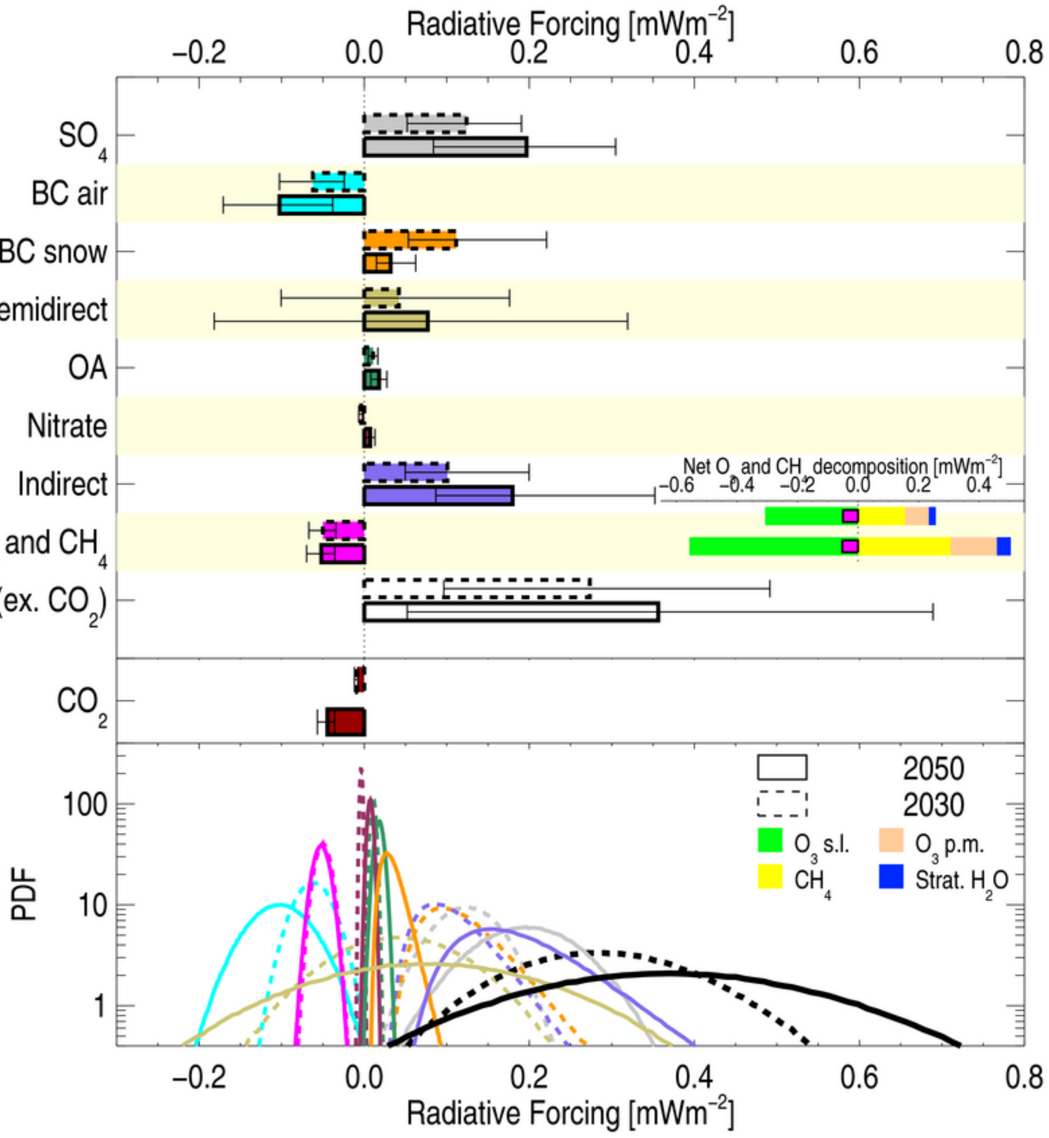

**Figure 2:** Effects in terms of global annual RF by component of shifting shipping routes from Suez to the Arctic route (upper) and uncertainty distributions (lower) for 2030 and 2050. Uncertainty bars are given for 5-95% ranges.

For the assumed linearized emission scenario described above, and with constant emissions after 2050, we calculated the response in global mean temperature (Fig. 3) over two centuries in order to capture the various timescales of the different components.

Shifting shipping from Suez to Arctic initiates responses of very different magnitudes and signs. A group of small warming effects (nitrate, OA and stratospheric $H_2O$) can be seen in Fig. 3. BC on snow and ice has a maximum warming effect around 2040 and declines thereafter due to reduced ice cover. After this time, the warming from methane, primary mode $O_3$, sulfate, semi-direct effect of BC and indirect aerosol effect dominates. Strong cooling effects from changes of direct aerosol effect of BC and $O_3$ are found. In a separate category, we find the negative $CO_2$ response which steadily grows larger. The net effect of all these contributions is a warming for the first one and a half centuries, which thereafter switches to cooling due to the long response time and dominant effect of $CO_2$. As shown in the inset figure, accounting for uncertainties (5-95%) – based on uncertainties in RF from SLCFS (Fig. 2), in $CO_2$ response and in climate sensitivity – shows that the warming period may last up to several centuries but also that the possibility of a net cooling effect from the start cannot be ruled out.

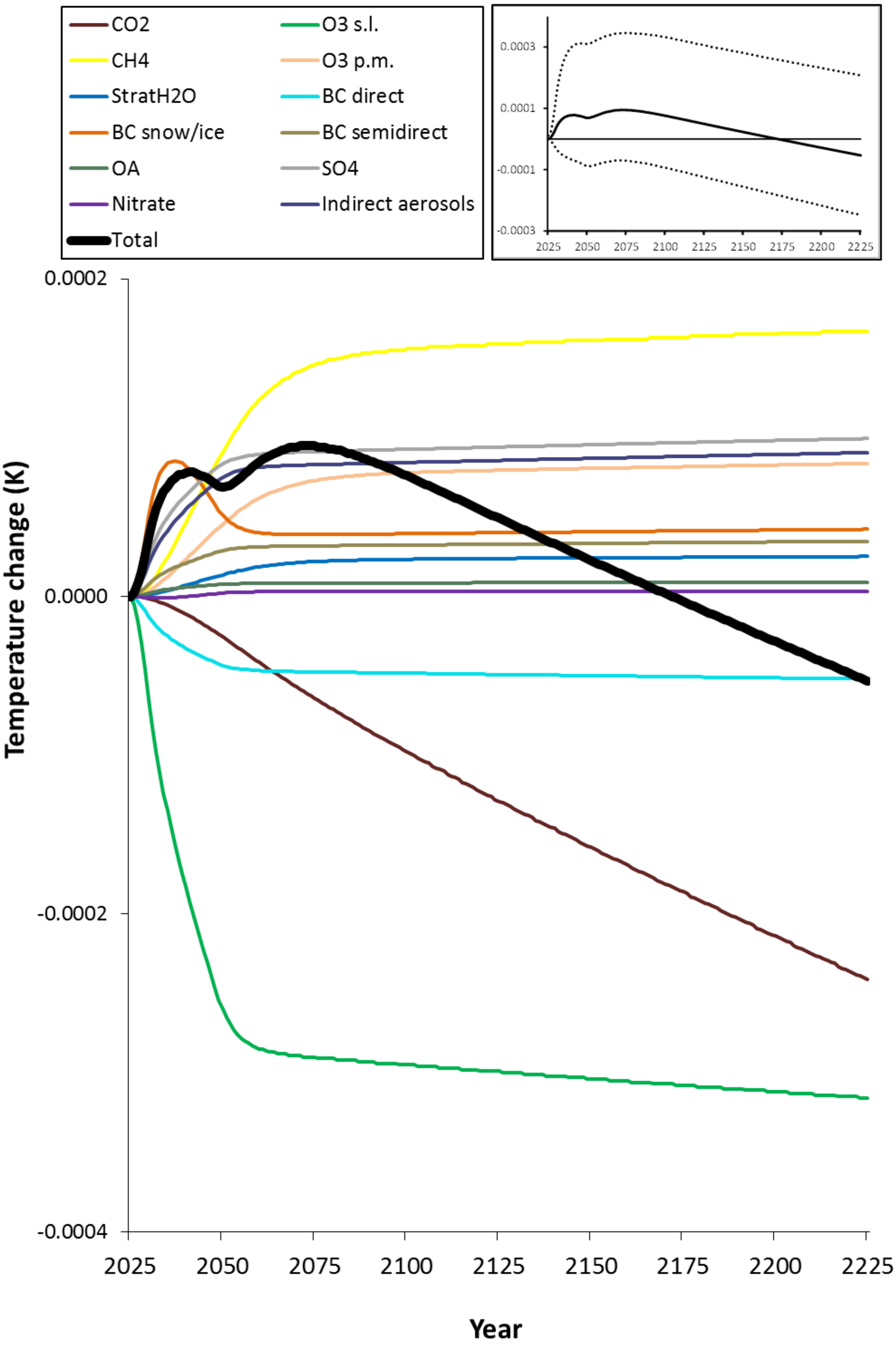

**Figure 3:** Development in global mean temperature by component and as total net effect including uncertainties.

# Conclusions

The current net impact of SLCFs from shipping both globally and in the Arctic is a cooling. We find that SLCFs from shipping most likely will contribute to Arctic and global warming from 2004-2030. This is mainly due to reduced cooling impact of sulfate aerosols and clouds as sulfur emissions from ships are reduced. Phasing in of existing IMO regulations on sulfur are efficient in reducing particle pollution both globally and in the Arctic. The tradeoff is that it leads to a warming. Though black carbon emissions from shipping are small, measures are favored by both reductions in air pollution and a cooling effect. The study finds an important contribution from black carbon in the Arctic in 2030, especially black carbon on snow and ice which efficiently absorb solar radiation warming the surface.

Shifting shipping from Suez to Arctic initiates responses of very different magnitudes and signs. The net effect is a warming for the first one and a half centuries, which thereafter switches to cooling due to the long response time and dominant effect of $CO_2$. Reducing emissions at low latitudes and introducing emissions in the Arctic adds complexity to assessments of climate impacts of future shipping routes. A question that needs to be addressed by policy makers is how to weight the Suez route with higher fuel costs, higher $CO_2$ emissions with its long-term climate consequences vs the Arctic route with a century scale warming but large inherent uncertainties due to SLCFS.

## References

Corbett, J., Lack, D., Winebrake, J., Harder, S., Silberman, J., and Gold, M.: Arctic shipping emissions inventories and future scenarios, Atmospheric Chemistry and Physics, 10, 9689-9704, DOI 10.5194/acp-10-9689-2010, 2010.

Dalsøren, S. B., Samset, B. H., Myhre, G., Corbett, J. J., Minjares, R., Lack, D., and Fuglestvedt, J. S.: Environmental impacts of shipping in 2030 with a particular focus on the Arctic region, Atmos. Chem. Phys., 13, 1941-1955, doi:10.5194/acp-13-1941-2013, 2013.

Fuglestvedt, J., S. Dalsøren, B. H. Samset, T. Berntsen, G. Myhre, L. I. Eide, M. S. Eide, J., T. F. Bergh, Ø. Hodnebrog, The climate penalty of Arctic shipping. In prep 2014.

Peters, G. P., Nilssen, T. B., Lindholt, L., Eide, M. S., Glomsrød, S., Eide, L. I., and Fuglestvedt, J. S.: Future emissions from shipping and petroleum activities in the Arctic, Atmos. Chem. Phys., 11, 5305-5320, doi:10.5194/acp-11-5305-2011, 2011.

Ødemark, K., Dalsøren, S. B., Samset, B. H., Berntsen, T. K., Fuglestvedt, J. S., and Myhre, G.: Short-lived climate forcers from current shipping and petroleum activities in the Arctic, Atmos. Chem. Phys., 12, 1979-1993, 10.5194/acp-12-1979-2012, 2012.