Annual Scientific Report 2016 ------- official, extended -------

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Long-Term Air Quality Monitoring Program
UNESCO World Natural Heritage "Geiranger Fjord", Norway

VERDSARV
Vestnorsk fjordlandskap

Jörg Löffler (University of Bonn, Germany)

Sponsored by:
Stiftinga Geirangerfjorden Verdsarv / Vestnorsk fjordlandskap - Geirangerfjordområdet

What is it about?
Monitoring program using permanent measurements of meteorological, micro-climatic and air quality variables

Objective: Understanding air quality variability from a long-term perspective

Cooperation (2016):
Bjørn Egil Pedersen (Norwegian Maritime Authority, Haugesund, Norway)
Hanne Weggeberg (Rambøll, Trondheim, Norway)
Eerik Järvinen at Rambøll Finland

Preface

This is a short scientific report on research activities within the Long-Term Air Quality Monitoring Program in the Geiranger area.

All data presented here are preliminary. Any interpretation should be used with caution.

Jörg Löffler (27.09.2016)

Technical Note

→ Abbreviations and units were used as introduced at the beginning of the report.
→ Color was used with associated variables whenever possible.

Abstract

According to the World Health Organization (2013) air pollution especially by traffic born particulate matter (PM) is a widespread problem, present wherever people live. The health effects of the finer fractions of PM, especially dust particles < 10 µm (PM10) and very fine particles even smaller than 2.5 µm (PM2.5) are well documented, and there is no evidence of a safe level of exposure or a threshold below which no adverse health effects occur. Even at relatively low concentrations the burden of air pollution on health is significant.

Our air quality monitoring program in the Geiranger area focuses on investigating the sources, the quantities, the mechanisms of spatio-temporal distribution, and their climatic driving forces in a long-term perspective.

After a pilot phase between May 2015 and September 2016 I here report on the first results.

Besides direct air pollution by SO_2 due to traffic, which was shown to be a good indicator of the activity of any type of combustion engine, PM was found to play the major role in contaminating the area.

Here I deliver a set of examples how air quality develops under certain climatic periods.

The findings will serve as a reference for future development.

Introduction (I)

Air pollution especially by dust particles is estimated to cause deaths directly, and it has been shown how the adverse effects of ultrafine air particles are linked to their ability to gain access to the lung and systemic circulation, where toxic components lead to tissue damage and inflammation (Nel 2005). It has since been an intense debate at political levels worldwide to limit the amount of air pollutants brought to the human environment in order to help to prevent mortality by particulate matter (WHO 2013).

Nel, A. (2005): Air Pollution-Related Illness: Effects of Particles. Science 308: 804-806. DOI: 10.1126/science.1108752

World Health Organization (WHO) (2013): Health Effects of Particulate Matter. WHO Regional Office for Europe. Copenhagen.

Direct Citation of WHO (2013: 6): ***"What are the health effects of PM? PM10 and PM2.5 include inhalable particles that are small enough to penetrate the thoracic region of the respiratory system. The health effects of inhalable PM are well documented. They are due to exposure over both the short term (hours, days) and long term (months, years) and include:***

- ***respiratory and cardiovascular morbidity, such as aggravation of asthma, respiratory symptoms and an increase in hospital admissions;***
- ***mortality from cardiovascular and respiratory diseases and from lung cancer.***

There is good evidence of the effects of short-term exposure to PM10 on respiratory health, but for mortality, and especially as a consequence of long-term exposure, PM2.5 is a stronger risk factor than the coarse part of PM10 (particles in the 2.5–10 µm range). All-cause daily mortality is estimated to increase by 0.2–0.6% per 10 µg/m3 of PM10 (6,7). Long-term exposure to PM2.5 is associated with an increase in the long-term risk of cardiopulmonary mortality by 6–13% per 10 µg/m3 of PM2.5 (8–10). Susceptible groups with pre-existing lung or heart disease, as well as elderly people and children, are particularly vulnerable. For example, exposure to PM affects lung development in children, including reversible deficits in lung function as well as chronically reduced lung growth rate and a deficit in long-term lung function (4). There is no evidence of a safe level of exposure or a threshold below which no adverse health effects occur. The exposure is ubiquitous and involuntary, increasing the significance of this determinant of health. At present, at the population level, there is not enough evidence to identify differences in the effects of particles with different chemical compositions or emanating from various sources (11). It should be noted, however, that the evidence for the hazardous nature of combustion-related PM (from both mobile and stationary sources) is more consistent than that for PM from other sources (12). The black carbon part of PM2.5, which results from incomplete combustion, has attracted the attention of the air quality community owing to the evidence for its contribution to detrimental effects on health as well as on climate. Many components of PM attached to black carbon are currently seen as responsible for health effects, for instance organics such as PAHs that are known carcinogens and directly toxic to the cells, as well as metals and inorganic salts. Recently, the exhaust from diesel engines (consisting mostly of particles) was classified by the International Agency for Research on Cancer as carcinogenic (Group 1) to humans (13). This list also includes some PAHs and related exposures, as well as the household use of solid fuels (14,15)."

Introduction (II)

Direct Citation of WHO (2013: 7): "*What is the burden of disease related to exposure to PM? It is estimated that approximately 3% of cardiopulmonary and 5% of lung cancer deaths are attributable to PM globally. In the European Region, this proportion is 1–3% and 2–5%, respectively, in various subregions (16). Results emerging from a recent study indicate that the burden of disease related to ambient air pollution may be even higher. This study estimates that in 2010, ambient air pollution, as annual PM2.5, accounted for 3.1 million deaths and around 3.1% of global disability-adjusted life years (17). Exposure to PM2.5 reduces the life expectancy of the population of the Region by about 8.6 months on average. Results from the scientific project Improving Knowledge and Communication for Decision-making on Air Pollution and Health in Europe (Aphekom), which uses traditional health impact assessment methods, indicate that average life expectancy in the most polluted cities could be increased by approximately 20 months if the long-term PM2.5 concentration was reduced to the WHO (AQG) annual level ...*"

World Health Organization (WHO) (2013): Health Effects of Particulate Matter. WHO Regional Office for Europe. Copenhagen.

Secondary Citations (by Numbers; see above):

4. Exposure to air pollution (particulate matter) in outdoor air. Copenhagen, WHO Regional Office for Europe, 2011 (ENHIS Factsheet3.3)
6. Air quality guidelines: global update 2005. Particulate matter, ozone, nitrogen dioxide and sulfur dioxide. Copenhagen, WHO Regional Office for Europe, 2006
7. Samoli E et al. Acute effects of ambient particulate matter on mortality in Europe and North America: results from the APHENA Study. Environmental Health Perspectives, 2008, 116(11):1480–1486.
11. Stanek LW et al. Attributing health effects to apportioned components and sources of particulate matter: an evaluation of collective results. Atmospheric Environment, 2011,45:5655–5663.
12. Health relevance of particulate matter from various sources. Report of a WHO Workshop. Copenhagen, WHO Regional Office for Europe, 2007
14. Some non-heterocyclic polycyclic aromatic hydrocarbons and some related exposures. Lyons, International Agency for Research on Cancer, 2010 (IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, Vol. 92) (15. Household use of solid fuels and high-temperature frying. Lyons, International Agency for Research on Cancer, 2010 (IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, Vol. 95)
16. Cohen AJ et al. Urban air pollution. In: Ezzati M et al., eds. Comparative quantification of health risks. Global and regional burden of disease attributable to selected major factors. Geneva, World Health Organization, 2004, 2(17):1354–1433
17. Lim SS et al. A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. Lancet, 2012, 380: 2224-2260.

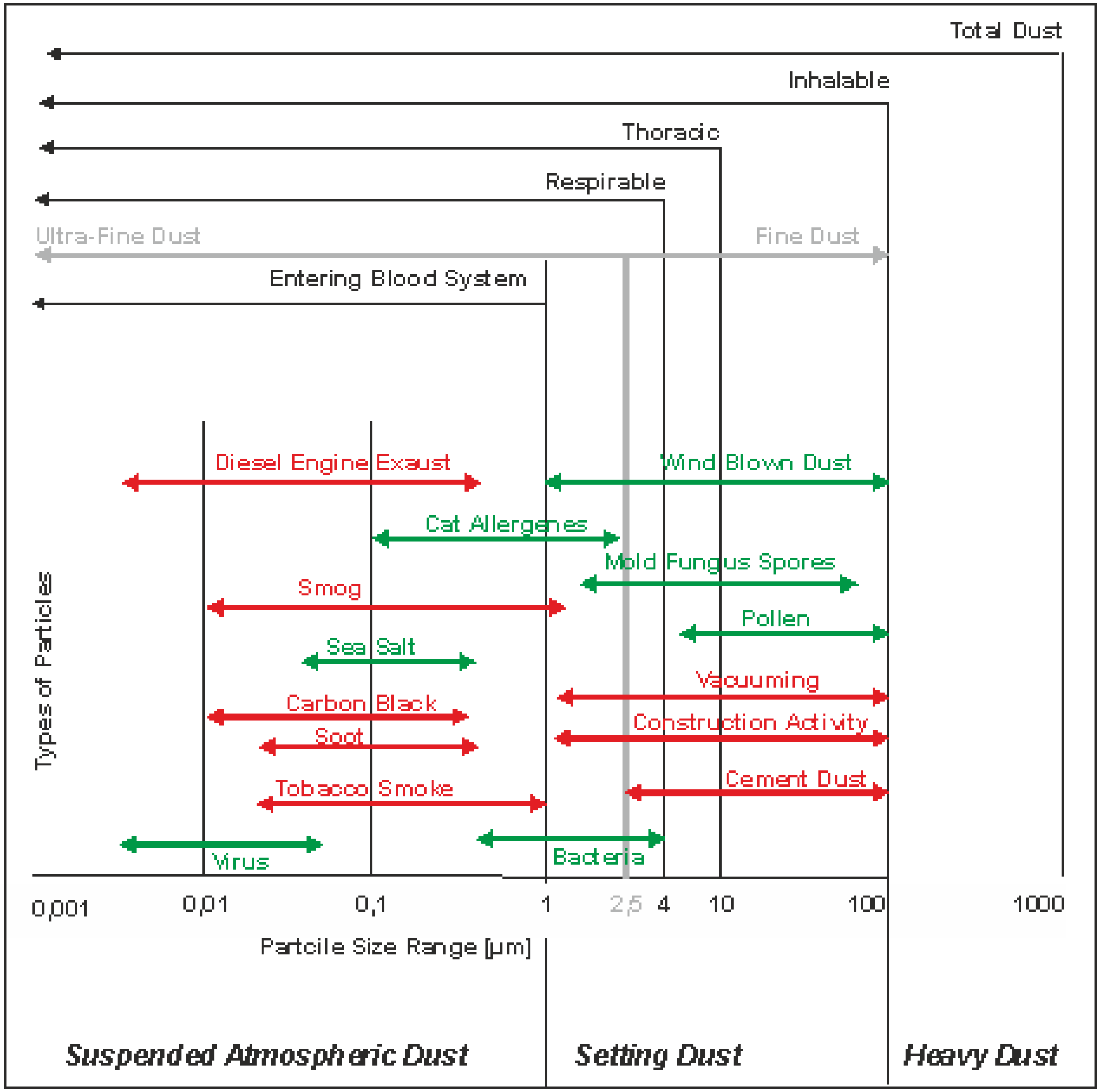
Air Quality Variables (Matter):

Particulate Matter (PM) is a measure of dust particles with an aerodynamic diameter of smaller than x micrometers [µm].

We used the following PMx fractions: PM100, PM10, PM4, PM2.5, and PM1 which allow to roughly detect their potential origin, and which are important measures concerning the impact of dust on human health.

Some particulates occur naturally. Human activities such as burning of fossil fuels in vehicles or coal combustion also generate significant amounts of particulates.

Equipment used: TSI DustTrack Pro, USA.



Air Quality Variables (Gases):

Sulphur Dioxide (SO_2) is a colorless gas which reacts on the surface of a variety of airborne solid particles, is soluble in water, and can be oxidized within airborne water droplets. Annual mean concentrations in major cities are nowadays below 100 µg/m³ with typical mean values in the range of 15-50 µg/m³. Hourly peak values can be 1000-2000 µg/m³. Natural background is about 5 µg/m³. An important sources of SO_2 is fossil fuel combustion. Coal burning is the single largest man-made source of SO_2 accounting for about 50% of annual global emissions, with oil burning accounting for a further 25-30%.

Source: http://www.air-quality.org.uk

Equipment used: AQMesh, Environmental Instruments, UK.

Explanatory Climate Variables:

Air Temperature: T [°C]

Relative Air Humidity: RH [%]

Maximum Wind Speed (mxWS) [m/s]

Wind Direction: WD [°]

Air Pressure: AP [hPa]

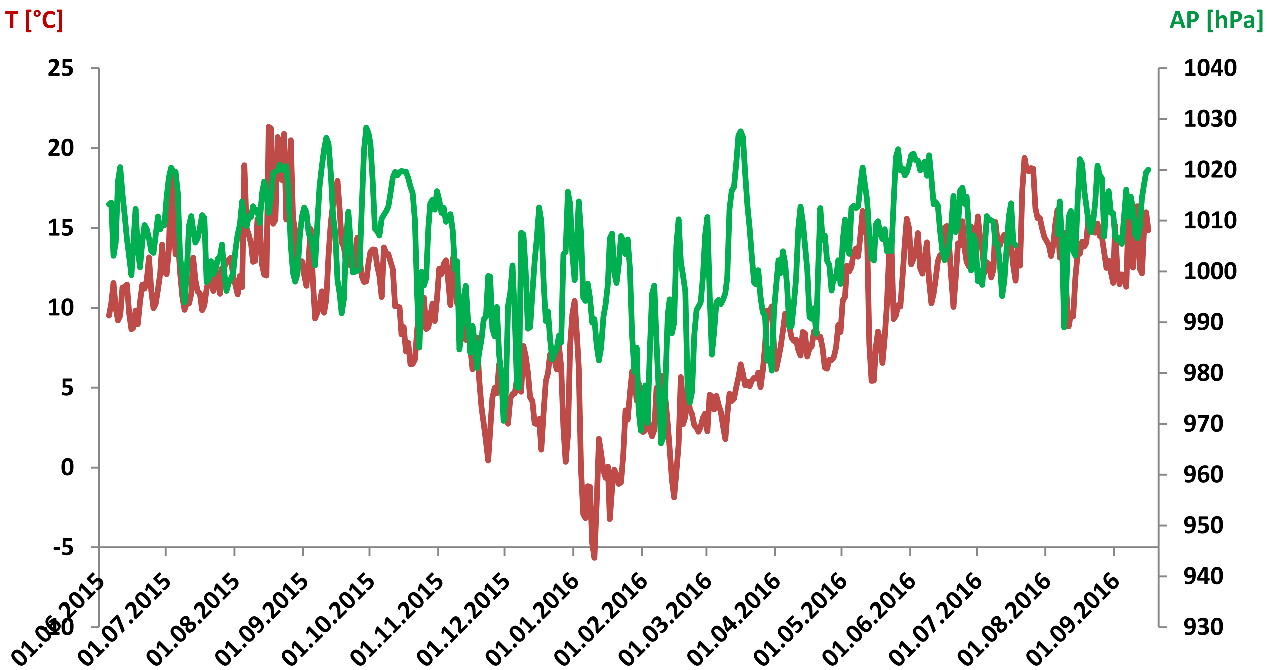
Precipitation (P), only liquid (rain, melting snow) [mm]

Temporal Resolution of Measurements:

Permanent Stationary Recordings = Hourly Data,
for the analysis also aggregated to daily values.

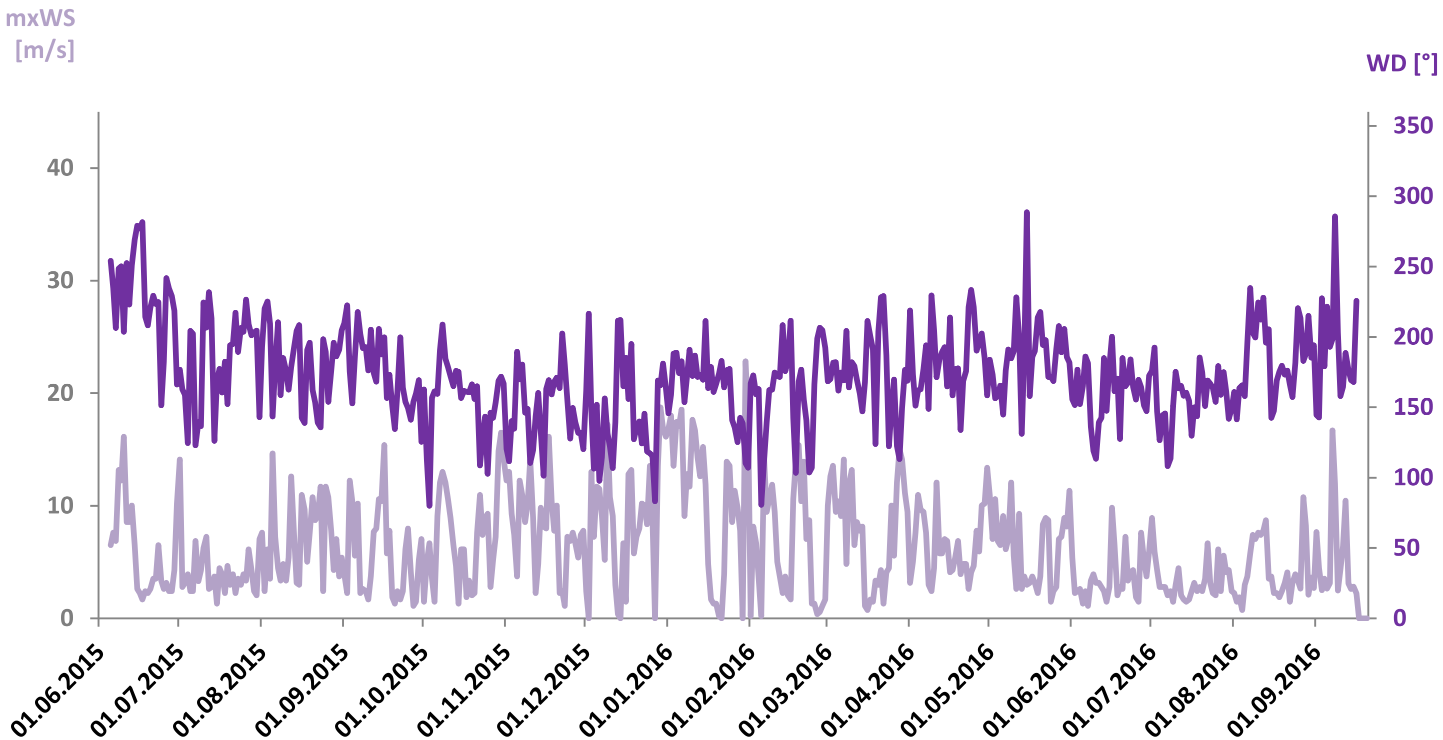
Equipment used: ADL-MX, Meier NT (D); Thies Clima (D); Skye (UK).

Geiranger (G): Daily Average Temperature (T) and Air Pressure (AP)



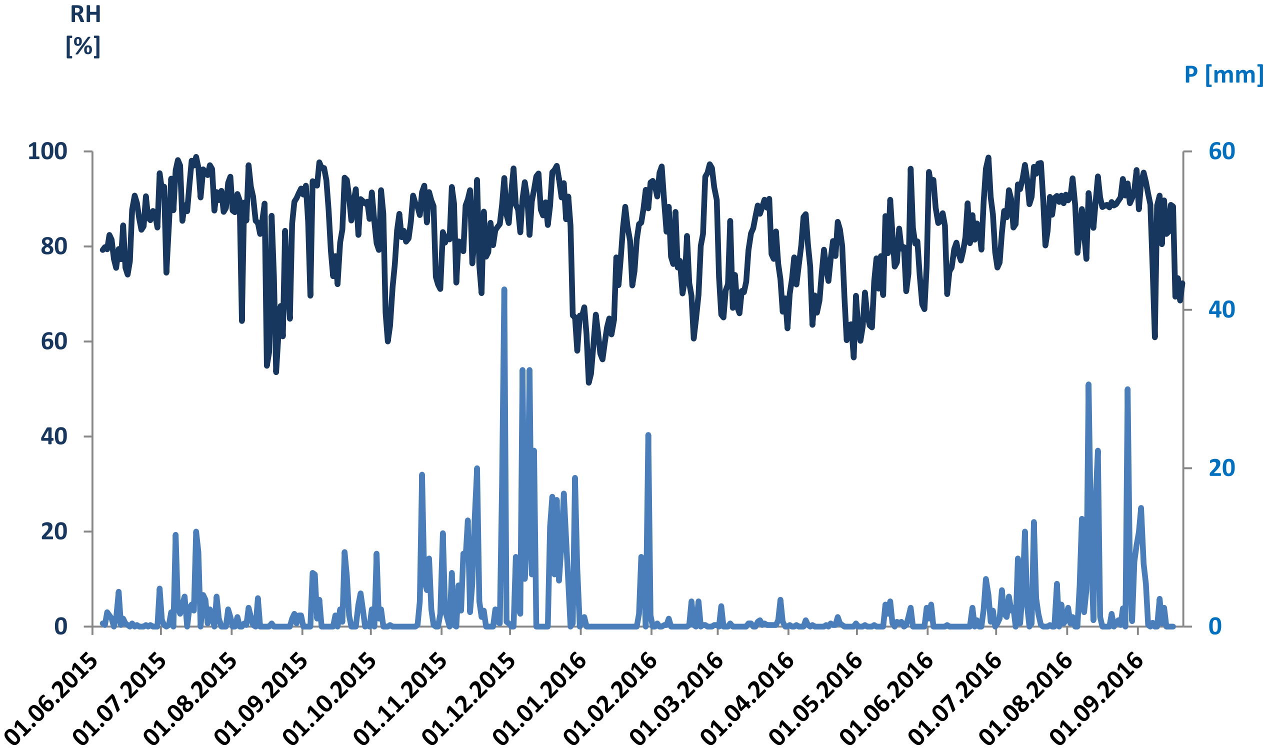
Air pressure and air temperature follow the course of the weather variability of the Northern Atlantic driven by Westerlies and Gulf Stream. The mountain topography has a predominantly expressed effect on temperature by a) the Föhn-Effect leading to falling warm dry winds from the South, when under low air pressure systems the mountains are blocking the south-western cyclones from the Atlantic ocean, and b) Nocturnal Cold Air Flow usually in combination with expressed high pressure systems and resulting inversion climate, which leads to relatively low temperatures at the valley bottom.

Geiranger (G): Daily Max. Wind Speed (mxWS) and Avarage Wind Direction (WD)



Wind directions are from the South mainly, with a variety of modifications from more eastern or western components. As to the direction of the valley, southern winds are strongest, especially during the winter. But there is a high variability of wind conditions, and stable and constant winds are rare over longer periods. Wind speeds are very low during inversion weather, while during Föhn wind speeds are highest with elevation, decreasing to the valley bottom.

Geiranger (G): Daily Avarage Relative Humidity (RH) and Precipitation Sum (P)



P(Sep15-Sep16) = 931.7 mm

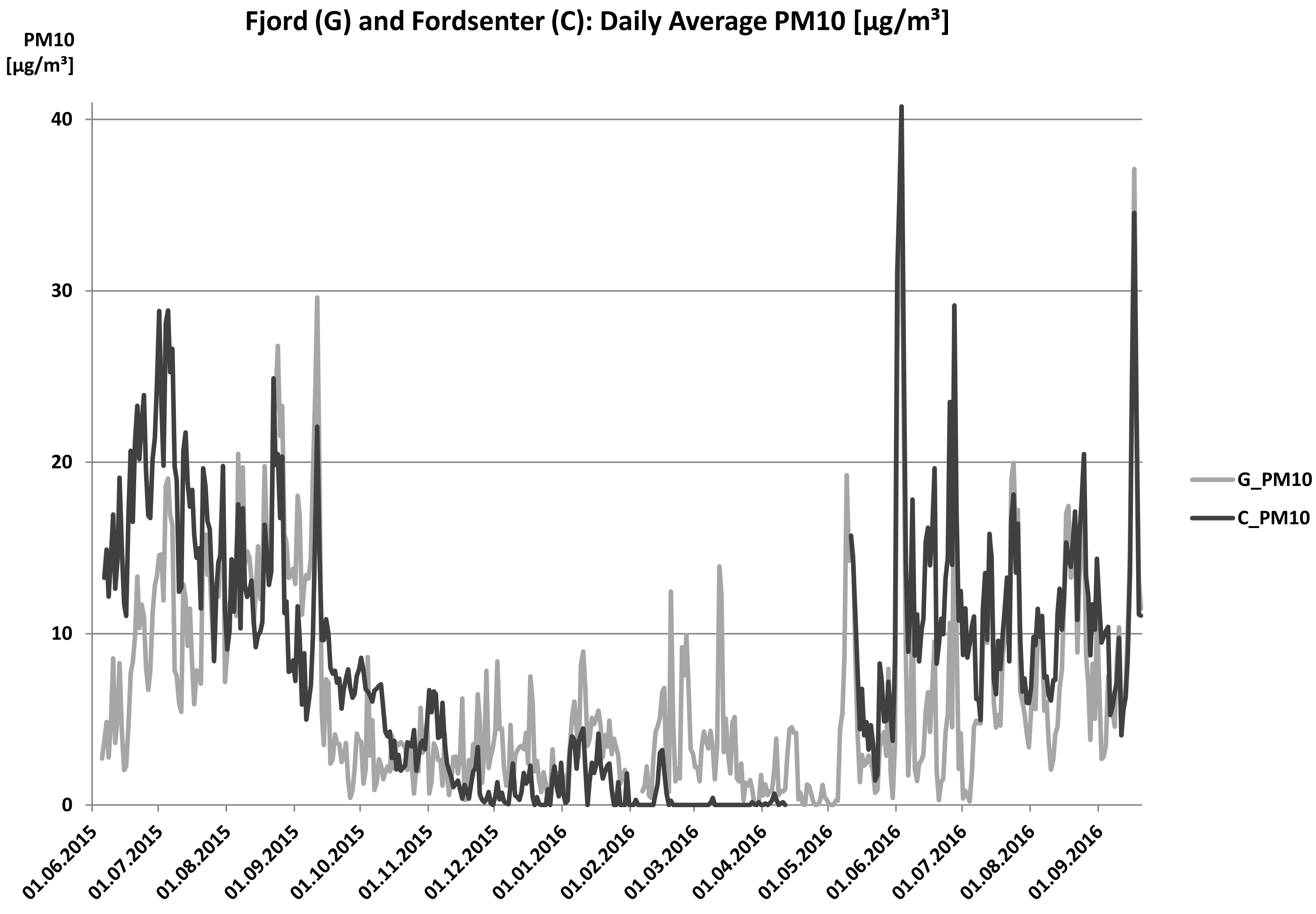
Precipitation is connected to the location in the northen Atlantic but varies locally along the elevational gradient, and temporally with season and from year to year. Relative air humidity is extremely variable with temperature, but most pronounced under inversion climate and cold air streams during the summer period.

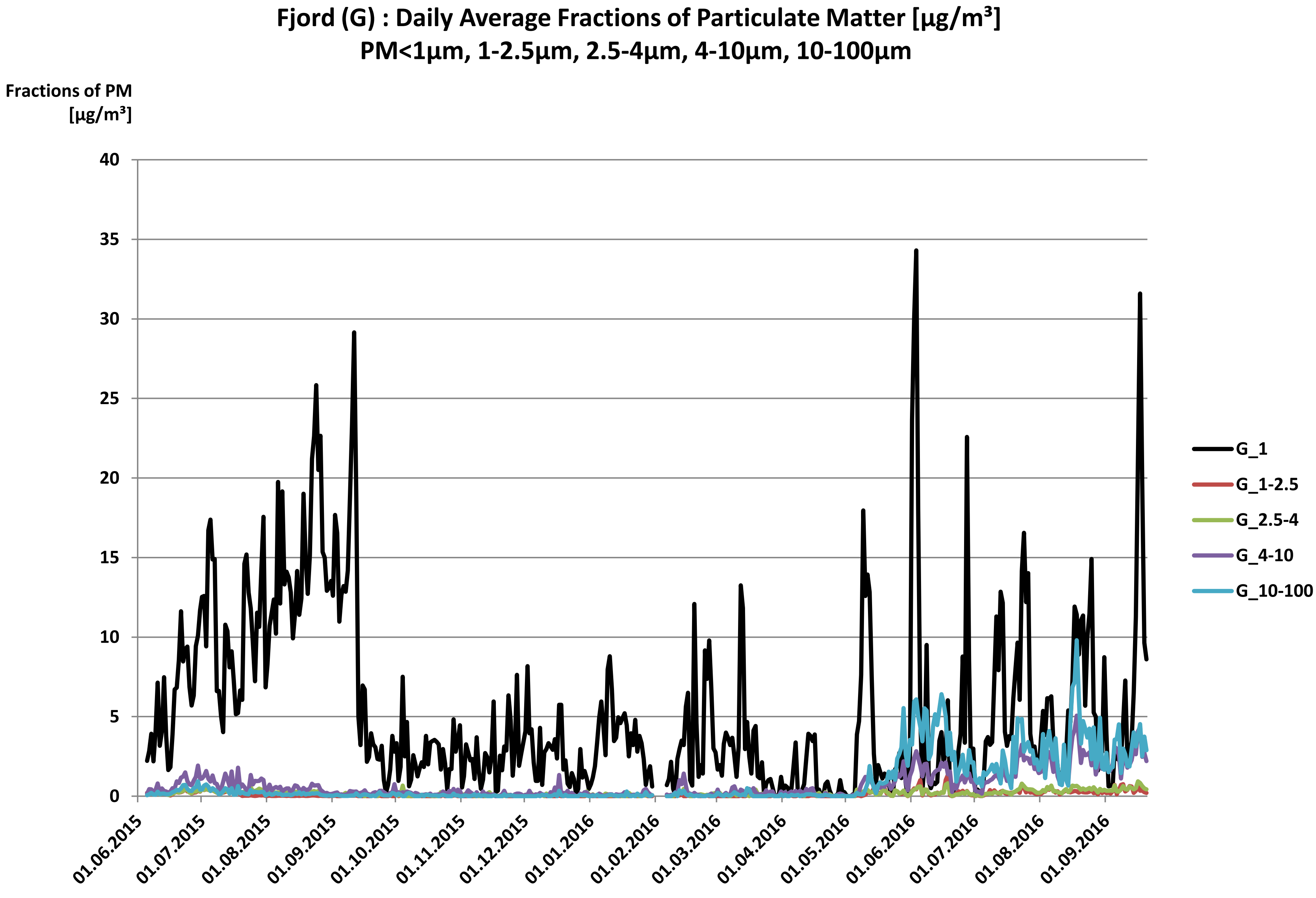
Year-to-Year Variability, Elevational Gradient, and Fractions of Particulate Matter

Dust track started in May 2015, and data are available from two stations +/- continuously since 01.06.2015.

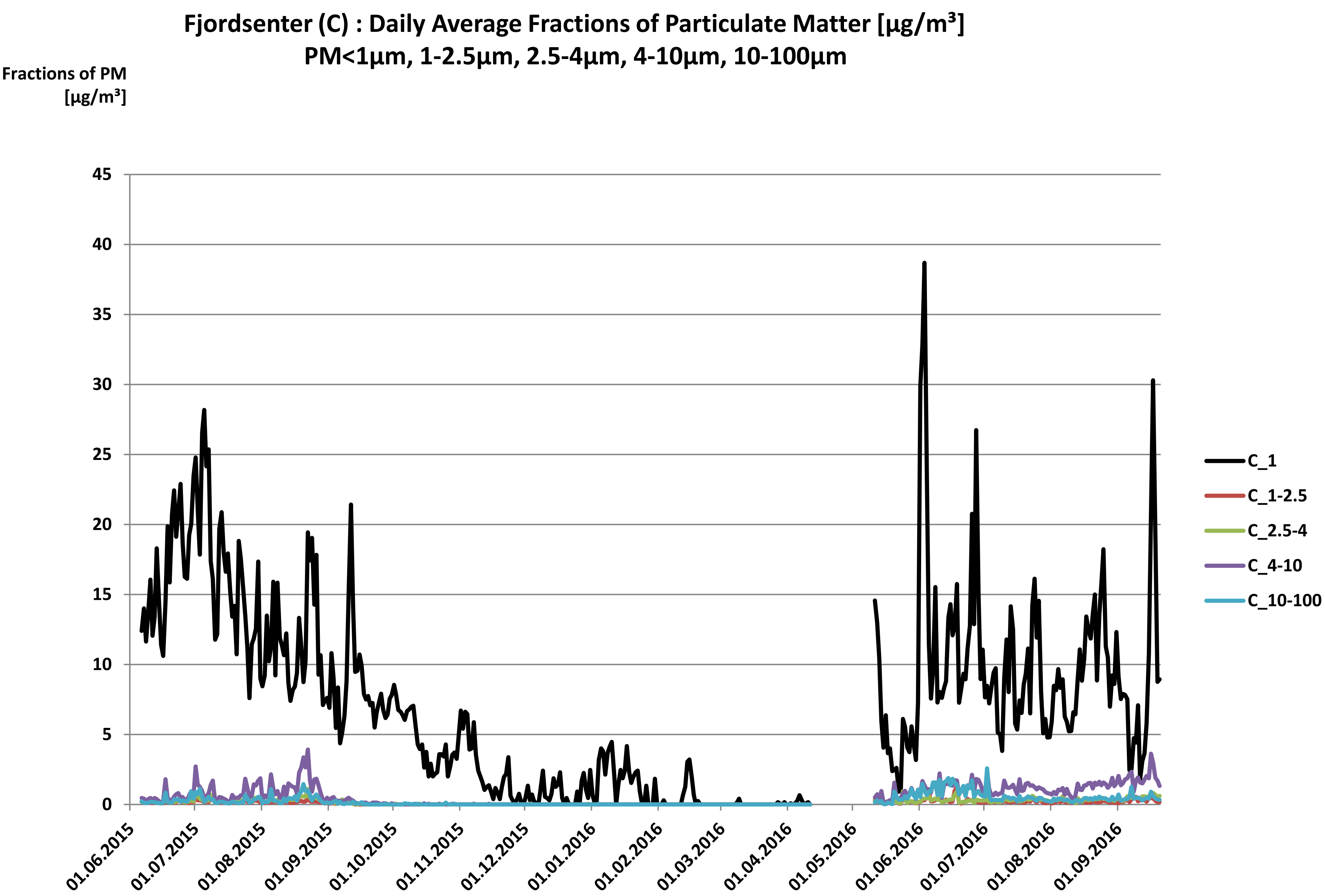
PM10 seems to accumulate over the entire summer period in the valley as tracked simultanuously at two stations along the elevational gradient from Fjord level to the Fjordsenter. Summer of 2015 had stronger cumulative effects than summer of 2016 in both, absolute minimum of dust concentration, and the period during which the pollution kept at a constantly high level. This was probably due to complex differences in weather conditions and timing and intensity of pollution.

Composition of different fractions of PM at the two different stations also shows that there was much higher coarse dust concentration at the lower elevations, but by far the major proportion of dust fractions was PM1. These finest particles were at a relatively high level of pollution throughout the summer periods of 2015, and 2016.


Fjord (G) and Fordsenter (C): Daily Average PM10 [µg/m³]
PM10
[µg/m³]
40
30
20
10
0
01.06.2015
01.07.2015
01.08.2015
01.09.2015
01.10.2015
01.11.2015
01.12.2015
01.01.2016
01.02.2016
01.03.2016
01.04.2016
01.05.2016
01.06.2016
01.07.2016
01.08.2016
01.09.2016
G_PM10
C_PM10



Fjord (G) : Daily Average Fractions of Particulate Matter [µg/m³]
PM<1µm, 1-2.5µm, 2.5-4µm, 4-10µm, 10-100µm
Fractions of PM [µg/m³]
40
35
30
25
20
15
10
5
0
01.06.2015
01.07.2015
01.08.2015
01.09.2015
01.10.2015
01.11.2015
01.12.2015
01.01.2016
01.02.2016
01.03.2016
01.04.2016
01.05.2016
01.06.2016
01.07.2016
01.08.2016
01.09.2016
G_1
G_1-2.5
G_2.5-4
G_4-10
G_10-100



Fjordsenter (C) : Daily Average Fractions of Particulate Matter [µg/m³]
PM<1µm, 1-2.5µm, 2.5-4µm, 4-10µm, 10-100µm
Fractions of PM
[µg/m³]
45
40
35
30
25
20
15
10
5
0
01.06.2015
01.07.2015
01.08.2015
01.09.2015
01.10.2015
01.11.2015
01.12.2015
01.01.2016
01.02.2016
01.03.2016
01.04.2016
01.05.2016
01.06.2016
01.07.2016
01.08.2016
01.09.2016
C_1
C_1-2.5
C_2.5-4
C_4-10
C_10-100

Absolute Concentration of Particulate Matter (I)

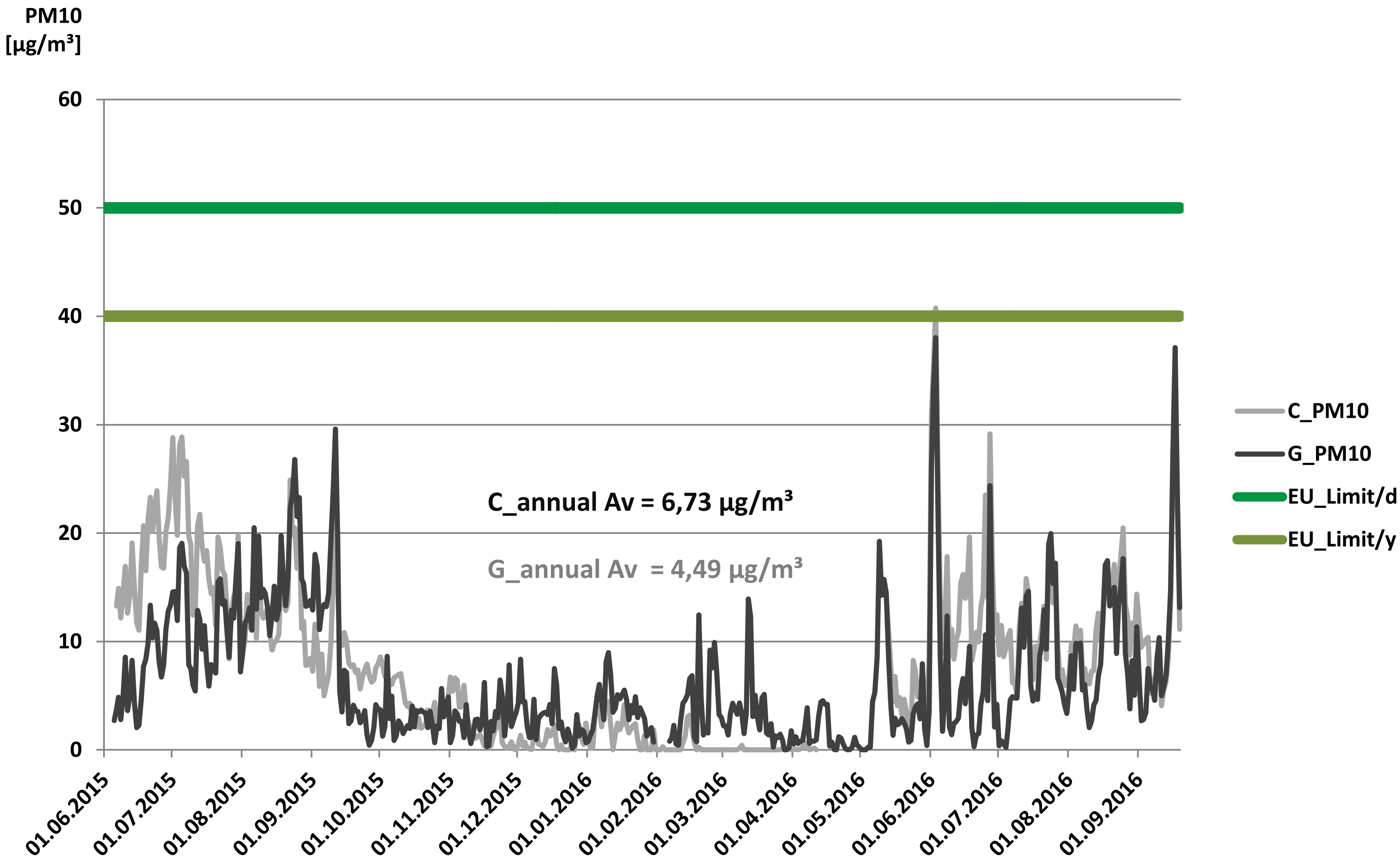
Compared to the legal daily limit of 50 µg/m³ PM10 according to the EU Directive 1999/30/EG from 22. April 1999 (which allows a maximum of 35 exceedances permitted each calendar year), our measured values at Fjord and Fjordsenter stations in the Geiranger area are relatively low. This holds true for each single station, and also for the entire course of the two years investigated. Daily maxima were below 30 µg/m³ with two exceptions in 2016 which reached about 40 µg/m³ at both stations.

Looking at the annual average of the pollution by PM10, our data show relatively low concentration of 4-7 µg/m³ at the two reference stations. As such, Geiranger mean annual air pollution is far below the legal annual limit of 40 µg/m³ PM10 (EU Directive 1999/30/EG).

Considering the long winter period during which there is also activity by PM10 release to the air, first and foremost by burning fire wood, in combination with the relative low maxima during the summer period, conditions in Geiranger are at a moderate European level of PM10.

I like to mention that here we compare air quality measures of highly populated places in the EU with a remote place which is ment to function as a unique place of nature in far distance to any industry, agglomeration, and other sources of dust pollution.

Fjord (G) and Fjordsenter (C): Daily and Annual Average (AV) PM10 [µg/m³]



Legal Daily Limit = 50 µg/m³; Legal Annual Limit = 40 µg/m²
(Max. number of exceedance permitted each calendar year = 35)
EU Directive 1999/30/EG , 22. April 1999

Absolute Concentration of Particulate Matter (II)

Compared to the legal daily limit of 25 µg/m³ PM2.5 according to the Australian National Standards (which allows no exceedances each calendar year), our measured values at Fjord and Fjordsenter stations in the Geiranger area are relatively high throughout the summer period. This holds true for each single station, and also for the entire course of the two years investigated. Daily averages were high at 15 - 20 µg/m³ with four exceedances at Fjord station and eight exceedances at Fjordsenter station in 2016.

Looking at the annual average of the pollution by PM2.5, our data show relatively high concentration of 4.9 - 5.2 µg/m³ PM2.5 at the two reference stations. As such, Geiranger mean annual air quality is getting quite close to the Australian legal annual limit of 8 µg/m³ PM2.5.

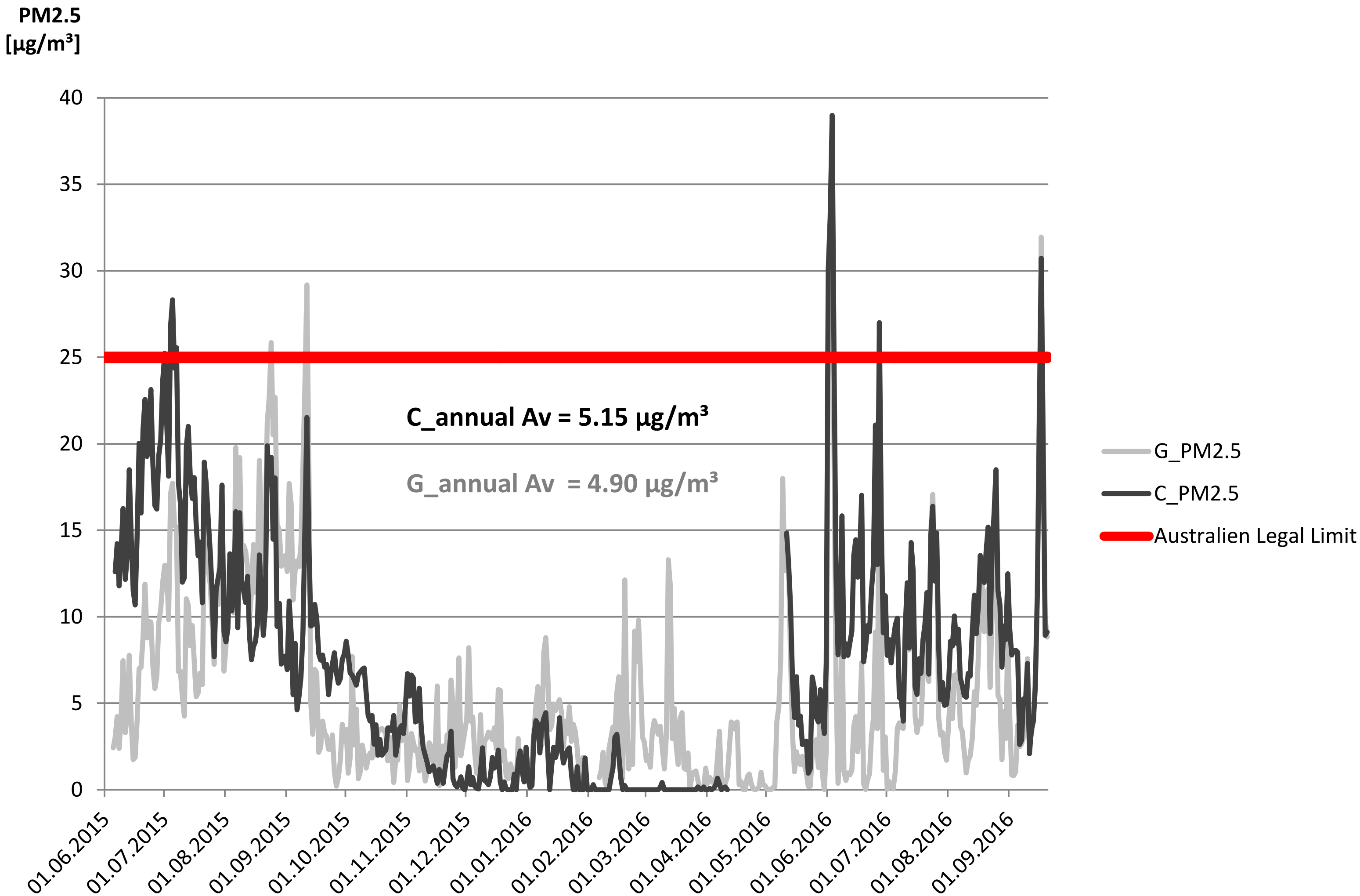
Considering the long winter period with relatively low emissions, air quality in Geiranger is critical.

Note: The Australian limits and regulations are according to the WHO standards for daily PM2.5, and even stricter for annual PM2.5, which was set to 10 µg/m³ by the WHO.

Australian Government – Department of the Environment and Energy (2005): National standards for criteria air pollutants in Australia – Air quality fact sheet. www.environment.gov.au. Retrieved 26.09.2016. "*Advisory reporting standard: 25 µg/m³ over a one day period; 8 µg/m³ over a one year period*".

World Health Organization [WHO] (2005): Air quality guidelines - global update 2005.

Fjord (G) and Fjordsenter (C): Daily and Annual Average (Av) PM2.5 [µg/m³]



Australian Daily Legal Limit = 25 µg/m³ (Nr. of exceedences allowed: none)
Australian Legal Annual Average Limit = 8 µg/m³

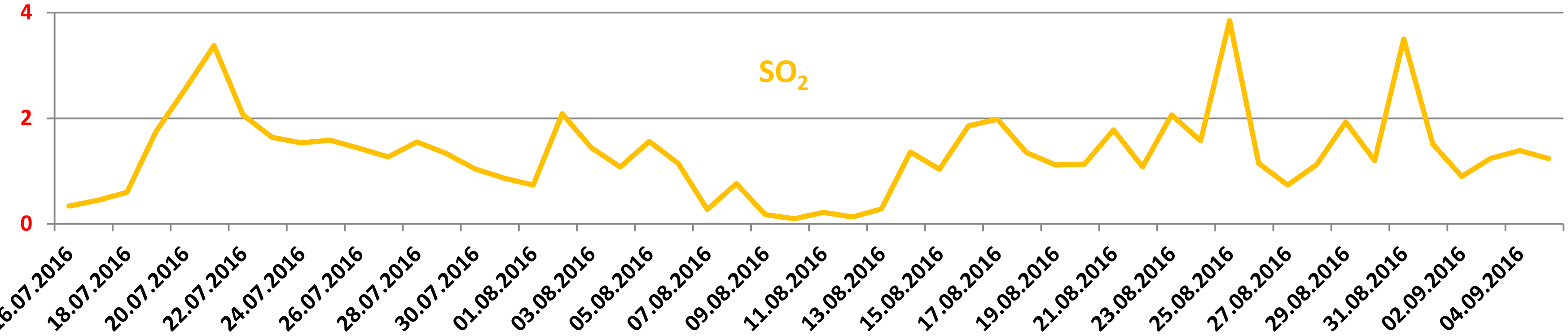
Absolute Concentration of Particulate Matter (III)

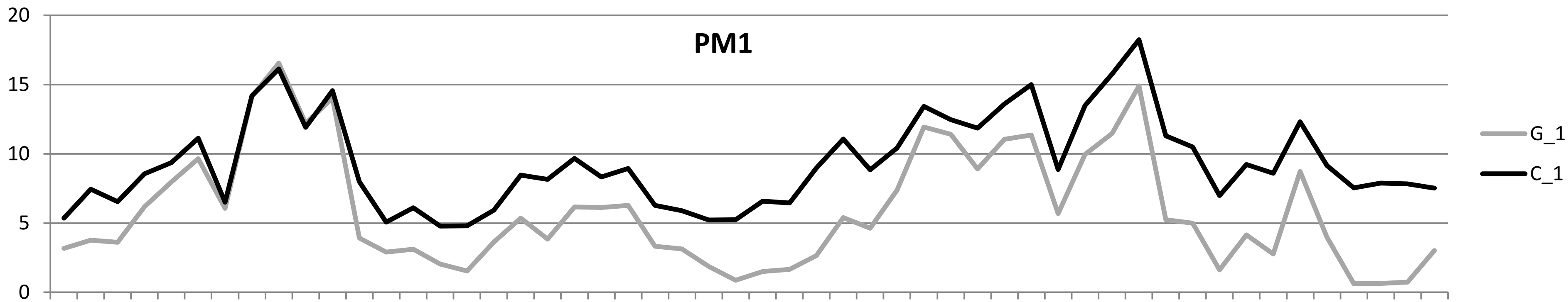
Until recently, there are no legal air quality standards, regulations or limits for PM1, worldwide.

Our measured values of PM1 at Fjord and Fjordsenter stations in the Geiranger area are relatively high throughout the summer period. This holds true for each single station, and also for the entire course of the two years investigated. Daily averages of PM1 were high at 10 - 20 µg/m³.

What has already been discussed for air pollution by PM2.5 holds true for PM1, since the majority of particles of PM2.5 are also finer than 1 µm.

As such, Geiranger hourly and daily PM1 concentration is high.





Air Pollution by SO_2

SO_2 was shown to be a suitable measure to track traffic activity.

Concentration of SO_2 with hourly maxima of below 10 µg/m³ was very little. We used an daily average of data from four independent sensors throughout the study period from July to September 2016. The graph illustrates SO_2 pollution and associated PM1 concentration. Synchronicity of PM1 and SO_2 was accurate, although SO_2 concentration was near its trace limit of the equipment used.

It seems that SO_2 pollution is not a serious problem in the area.

Summary of Scientific Results

During the period reported here, we found relatively high concentration of particulate matter of smaller than 1 µm of their aerodynamic diameter (PM1) as the major pollutants to the area of Geiranger.

This dust fraction is permanently suspended in the air over many weeks and is simply transported by circulating air along the entire valley where it seems to be trapped by inversion climate and steep surrounding mountains associated with only local air exchange.

Separating the various explanatory variables helped to explain certain conditions of pollution. To understand the entire system under different weather a complex approach is required. Decoupling of air pollution in space and time from its sources is the most challenging task for future scientific studies.

Our preliminary data need further scientific work before the suggested interpretations and conclusions can be generalized and advise policy makers in their actions.

Post Scriptum

While preparing this report, the Norwegian government has introduced national air quality goals for 2017 onwards. The goals are not legally binding and are based on health assessment carried out by the Norwegian Institute for Public Health. The limits are (annual means):

PM10: 20 µg/m^3 PM2.5: 8 µg/m^3

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