Name of research institute or organization:

Institut für Umweltgeowissenschaften, Universität Basel

Title of project:

Defining a criterion for free tropospheric air at Jungfraujoch

Project leader and team:

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Project description:

Since December 2009 two identical radon (^{222}Rn) monitors, built by ANSTO (Whittlestone and Zahorowski, 1998), have been working in parallel at Bern and on Jungfraujoch. At Bern, air is sampled at the Physics Institute, on the flat rooftop of a four storey building (sampling height 575 m a.s.l.), which is located on the edge of a bluff, about 20 m above the historical part of the city. At Jungfraujoch, air is aspired from outside the research station at 3454 m a.s.l. Horizontal distance between both stations is 60 km (Figure 1). Predominant wind directions on Jungfraujoch are NW and SE. Because of its altitude Jungfraujoch is considered a remote continental site, with most of the analysed air originating from the free troposphere (FT), but sometimes also influenced by air from the planetary boundary layer (PBL). The PBL influence has been studied before through the analysis of a one year record on decay products of ^{222}Rn and ^{220}Rn (Gäggeler et al., 1995), a 9-year aerosol record (Lugauer et al., 1998), a 2-year NO_y record (Zellweger et a., 2003) and a 14-year record on aerosol variables and trace gases (CO, NO_x, SO_2) (Collaud Coen et al, 2011). All mentioned analyses were based on measurements at Jungfraujoch and a careful data analysis in light of weather pattern observed in the larger region. Collaud Coen et al. (2011) further included measurements of specific humidity and CO from a site about 85 km WNW of Jungfraujoch. We take a different approach by restricting our analysis to situations when air passing over Jungfraujoch arrives from north of the Alpine ridge and simultaneously monitor ^{222}Rn at Jungfraujoch *and* in the PBL (Bern). ^{222}Rn is a short-lived noble gas ($t_{1/2}$ = 3.82 days), which is emitted (predominantly) from land at a rate that does not vary in space and time as much as that of anthropogenic tracers.

Figure 1. *Atmospheric ^{222}Rn sampling locations (in brackets: sampling height above sea level).*

Data analysis for the period from 01 Jan. 2010 to 28 Nov. 2011 includes four steps:

1. Normalisation of ^{222}Rn values for both stations to 1013 mbar and 0 $^{\circ}$C.
2. Half-hourly data are averaged for each full hour of day (UTC).
3. Hourly values selected when valid hour lies are available for both stations (14’463 hours).
4. From this set, selected all data (9’084 hours) when wind on Jungfraujoch came from sector north of mountain ridge (0- 45° and 225- 360°).

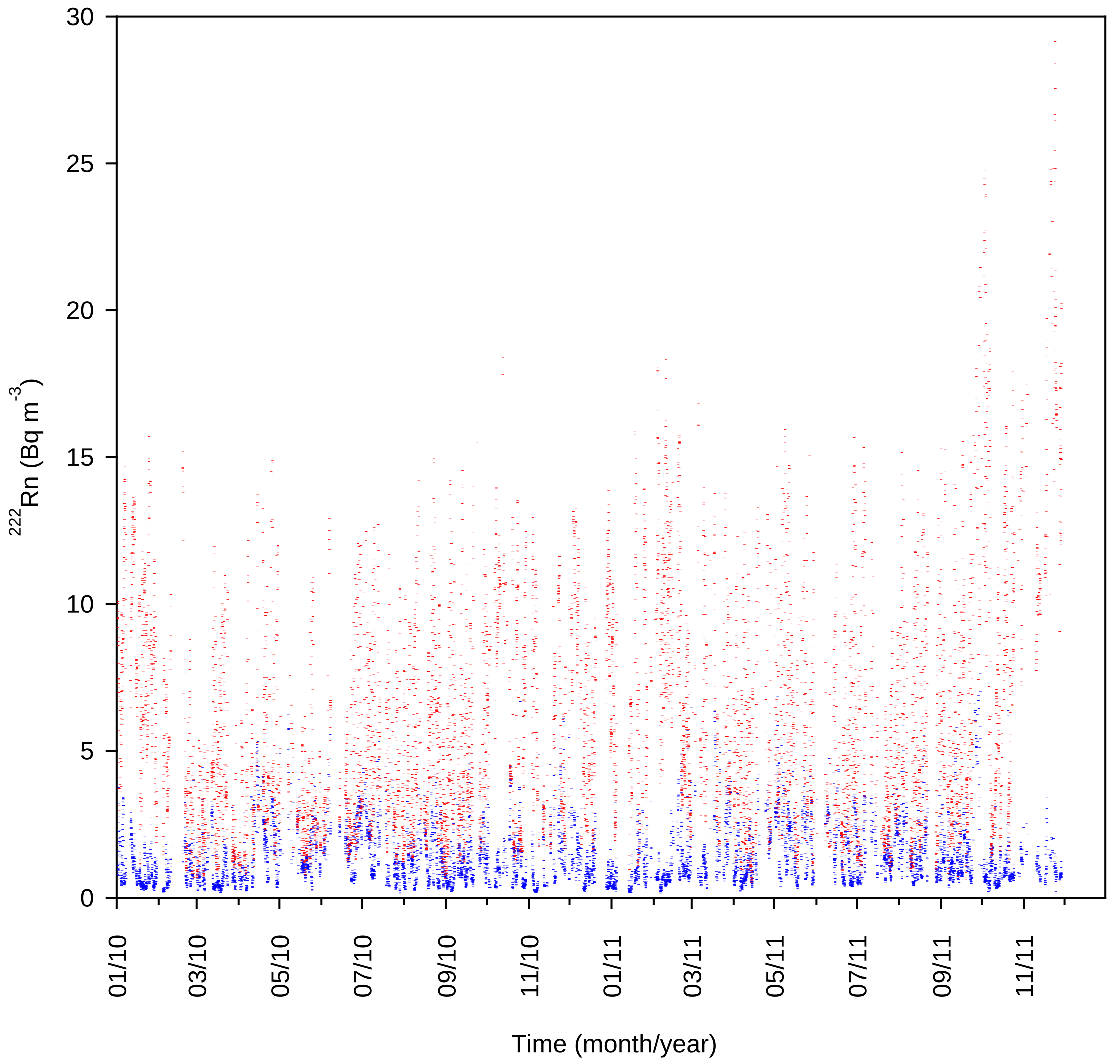

Figure 2. *Time series of ^{222}Rn activity concentrations in Bern (red) and on Jungfraujoch (blue) between 01 January 2010 and 28 November 2011, for situations when wind on Jungfraujoch blows from north of the Alpine ridge and when a value for both stations is available.*

We presume efficient mixing of PBL with FT air at Jungfraujoch when ^{222}Rn maxima at Jungfraujoch are close to ^{222}Rn minima at Bern. Such conditions did occur in every month of the year, but mostly from April to September. Prolonged periods with large differences in ^{222}Rn between both stations, indicating little or no exchange between PBL and FT at Jungfraujoch, were seen in both years in October, January and December 2010 and in February and November 2011. The most recent month with large differences in ^{222}Rn falls into the period of a persistent high pressure system over central Western Europe. In many parts of Switzerland November 2011 was the driest and also the sunniest November since recordings started 150 years ago (www.meteoschweiz.ch). Consequently, nocturnal inversions were strong and maybe also emissions of ^{222}Rn were larger because of the drier soil.

Is it possible to define a criterion for (predominantly) free tropospheric air at Jungfraujoch? One approach would be to define an upper limit for ^{222}Rn concentrations at Jungfraujoch below which air masses are considered to be part of the FT. However, any selection of a threshold for FT conditions would necessarily be arbitrary. The lower boundary of values tends to be higher from April to July, compared to other times of the year (Figure 2). A cautiously selected threshold value would classify most of the summer period as PBL influenced. Choosing a higher threshold would bear the un-quantified likelihood of including PBL influenced periods during other months. Further, the seasonal pattern bears some general resemblance between the years, but is certainly not the same in each year.

There were prolonged periods with large differences in ^{222}Rn concentrations between Jungfraujoch and Bern (Figure 2). During these periods, mixing of air masses from the PBL (Bern) to greater height (Jungfraujoch) must be strongly suppressed. Under such conditions we can assume that Jungfraujoch is in the FT. It may be possible to approach the identification of a selection criterion for FT situations at Jungfraujoch by asking what difference in ^{222}Rn concentrations would be necessary to indicate with some confidence that Jungfraujoch is in the FT. Differences in ^{222}Rn concentrations measured during the same hour at Bern and at Jungfraujoch have a frequency distribution that is supported by a set of 9’084 data points (Figure 3). It looks skewed toward small values. Its mode is between 1 and 2 Bq m^{-3}. A small proportion (0.016) of the data set is < 0, about half of all values are > 4 Bq m^{-3}. Such a distribution may result from the combination of two subsets of data with different means and standard deviations. As has been argued by other investigators before, Jungfraujoch is within the FT much of the time, but sometimes influenced by the PBL. Consequently, there should be a subset of values representing situations when Jungfraujoch is influenced by PBL air and when differences to ^{222}Rn concentrations at Bern are small; and a second subset representing situations when Jungfraujoch is dominated by the FT and differences in ^{222}Rn with Bern are large. This second subset of data would have a larger mean, but also a larger standard deviation because ^{222}Rn concentrations within the PBL cover a broad range of values, typically between 2 and 15 Bq m^{-3} (Figure 2). Based on these suppositions, we can try to estimate means, standard deviations and relative sizes for two normal (Gaussian) distributions so that their sum fits well with our observed distribution. Minimising the sum of squared residuals is the procedure of choice. Because the absolute uncertainty in observed frequency is proportional to the number of observations supporting it, we weigh the squared residuals by dividing them by the square root of the number of observations in each bin. For fitting means and standard deviations we make use of the “Solver” tool in Excel. Iteratively, we also change manually the relative sizes of the two subsets in steps of 0.05 either direction until a minimum is found for the sum of weighed squared residuals.

The result suggests that Jungfraujoch is influenced by PBL air during about a third of the time (0.35). Two thirds of the time (0.65) it is in the FT. Mean and standard deviation are 1.8 and 1.2 for the suggested PBL, and 6.7 and 3.7 for the suggested FT distribution, respectively (Figure 3). Based on these distributions we may now approximate a lower threshold for the difference in ^{222}Rn between Bern and Jungfraujoch above which we could say with 95 % certainty that Jungfraujoch is in the FT. This value is at 3.4 Bq m^{-3}. However, by rejecting observations below this value as PBL influenced, we also lose about 20 % of our FT data. Relaxing the threshold to 2.9 Bq m^{-3} would reduce the proportion of FT data lost to 15 %, but at the same time increase the fraction of PBL influenced data in our selection to 10 %.

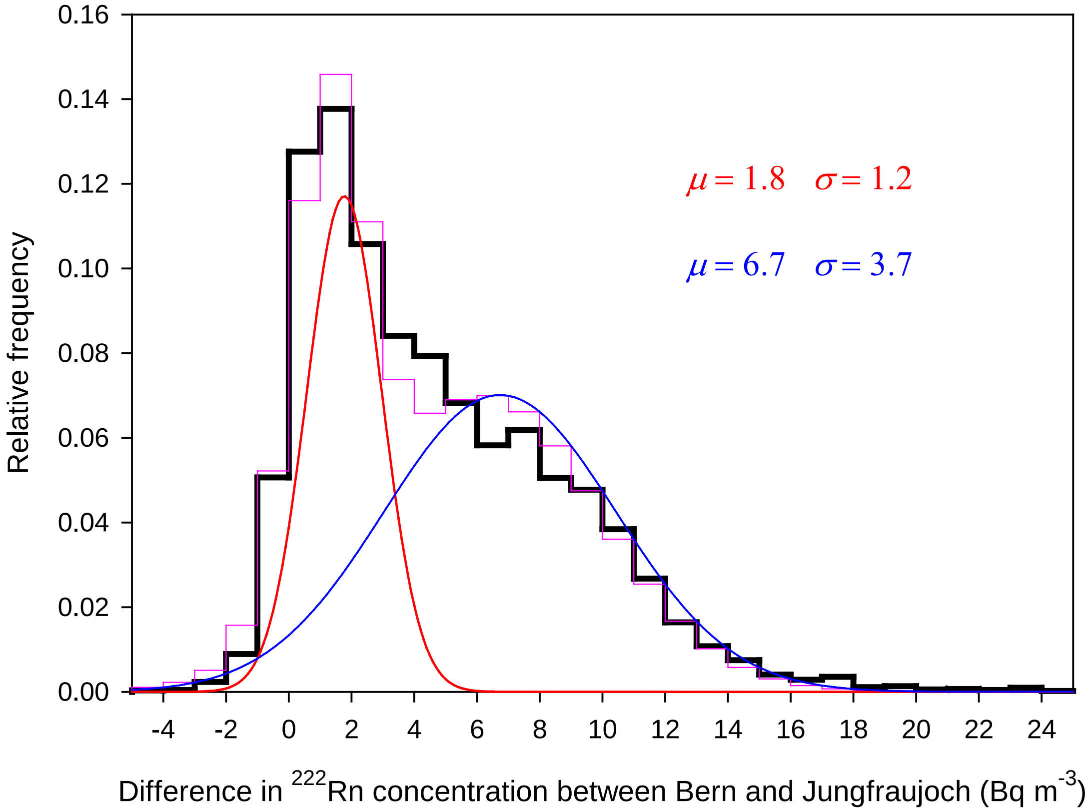

Figure 3. *Histogram of (black) differences in ^{222}Rn concentrations between Bern and Jungfraujoch and fitted normal distributions for presumably (red) PBL influenced situations and (blue) for situations when Jungfraujoch is in the FT. Addition of the fitted normal distributions results in the (pink) estimated histogram.*

Applying the threshold of 3.4 Bq m^{-3} to the past two years shows that measurements in the FT are possible at Jungfraujoch throughout the year (Figure 4). We can be confident (95 %) that during about half of the time when air masses crossed from north of the Alpine ridge this air was not influenced by PBL air. Reliable FT conditions occured during spring and summer about $^{2}/_{5}$ of the time, in autumn during $^{2}/_{3}$, and in winter during $^{3}/_{4}$ of the time.

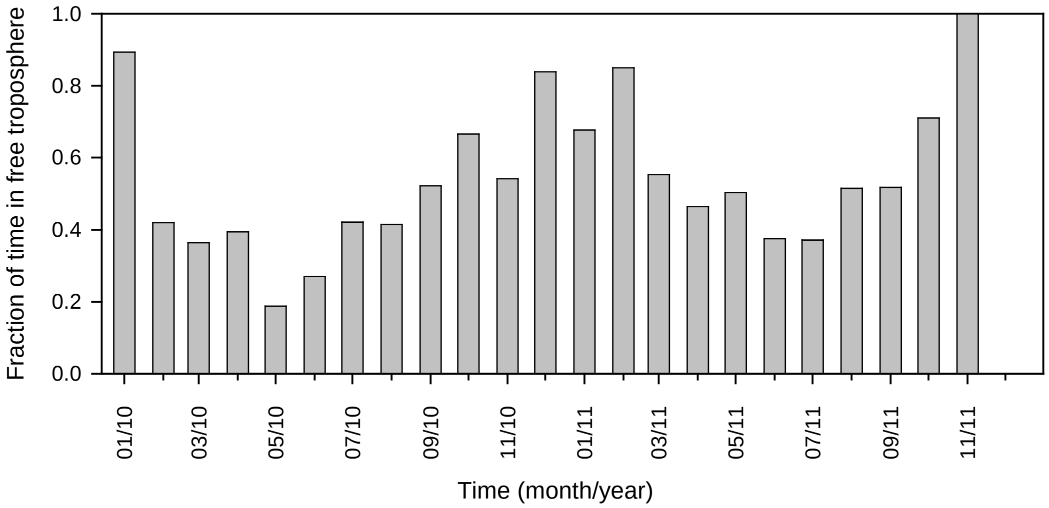

Figure 4. *Time series of monthly values for the fraction of time when ^{222}Rn concentration differences between Jungfraujoch and Bern were >3.4 Bq m^{-3}, so the fraction of time when Jungfraujoch can be said with 95 % confidence to have been in free tropospheric air.*

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Internet data bases:

http://radon.unibas.ch
http://pages.unibas.ch/environment

Collaborating partners/networks:

Group for Climate Gases, Empa Dübendorf

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