



Standard Observation SOATM_108

Dry deposition of N-components

Version 0.3

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NOTE: THIS PROTOCOL IS STILL UNDER REVIEW



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By the end of January 2026 the further work on the protocol was handed over to and executed by the provisional eLTER Head Office and Topic Centre on Interoperability of the emerging eLTER ERIC.

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0.3	Harmonized with SOATM_103	Aug 2026	S. Zacharias

SO variable overview

Habitat:

Applies to all eLTER habitat groups.

Variable(s):

- **Dry deposition of N-components:** data describing the atmospheric deposition of gaseous nitrogen (NH_3 , NO_2 , HNO_3 , HONO) and aerosol nitrogen (NH_4^+ , NO_3^-) during dry periods, including throughfall measurements in forest ecosystems and inferential model estimates for non-forest habitats

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1 Introduction

Nitrogen (N) fluxes as gasses and particles from the atmosphere during dry periods, due to gravity (sedimentation), impaction, and interception are determined. The magnitude is strongly influenced by the type of surfaces (leaves, needles, rocks, water, etc.), the humidity of surfaces, and the macro- and micrometeorology (stomata closure). Dry deposition occurs in various inorganic species such as gaseous NH_3 , HNO_3 , HONO , NO , NO_2 and aerosol NH_4^+ and NO_3^- , as well as in a range of organic molecules (Flechard et al. 2011).

Particularly in forests, dry deposition is a major pathway of atmospheric nitrogen input, yet it is difficult to quantify directly. Micrometeorological techniques such as eddy covariance and related flux measurement approaches can be used to estimate atmospheric nitrogen exchange, but these methods are technically demanding, costly, and require substantial expertise and maintenance. Consequently, they are not suitable as standard methods for routine application as an eLTER SO. Therefore, we propose a tiered approach. First, only the PRIME method (mandatory for eLTER Category-1 Sites with a focus on Atmosphere) uses additional measurements. Second, within the PRIME method, different methods for forest and non-forest ecosystems will be applied. For forests, ICP Forests published a protocol for dry deposition, which we will use in the eLTER RI (Clarke et al. 2022). Accordingly, dry deposition of nitrogen and canopy uptake of nitrogen compounds is measured using open field and canopy throughfall deposition samplers together with canopy budget models. For grassland, heath, and sparsely vegetated surfaces, we propose using concentration measurements together with inferential modelling (measurement - model fusion) (Flechard et al. 2011; Massad et al. 2010).

The BASIC method refers to existing modelling results derived from national or larger scale model-driven gridded data, e.g. the EMEP model (EMEP 2024).

2 BASIC method

The eLTER SO BASIC method provides quantitative dry nitrogen (N) deposition estimates using existing large-scale model outputs (Table 1). The scope is to complement N deposition in precipitation (see SOATM_103, Atmospheric deposition in precipitation) with dry N deposition data in order to give a more reliable estimate of the total N deposition to the focal ecosystem type at an eLTER Category 1 (if Atmosphere is not one of the focal spheres) and 2 site. No additional field measurements are required for the BASIC method.

Yearly, monthly, daily, and hourly gridded NetCDF files are available from the EMEP model on a $0.1^\circ \times 0.1^\circ$ longitude-latitude grid for the reported compounds. More information about the model runs and grid domain can be found in the references and definitions of compounds in the latest EMEP Status Report (EMEP 2024). The compounds of interest are dry deposition of oxidized and reduced N, available for different receptor types (deciduous forest, conifer forest, and seminatural vegetation). The latter should be used for all non-forest ecosystems, and weighted (per tree species share) averages should be applied for mixed forests. National data sources can be used alternatively but must be described in the metadata, including the EMEP model version and whether Type 1 or Type 2 data was used.

3 PRIME method

3.1 Scope and data product

The eLTER SO PRIME method records dry nitrogen (N) deposition through a tiered, habitat-specific approach combining field measurements with modelling (Table 2 and 3). The scope is to provide measured dry N deposition data to complement N deposition in precipitation (see SOATM_103,

Table 1: SOATM_108 BASIC method: raw data and data products to be analysed. Optional parameters are given in brackets.

Site category	2, or 1 if Atmosphere is not one of the focal spheres
Raw data	Gridded model output of dry deposition of oxidized and reduced N (NetCDF)
Data products	Dry deposition of oxidized N (mm) Dry deposition of reduced N (mm)

Atmospheric deposition in precipitation) for a more reliable estimate of total N deposition to the focal ecosystem type at an eLTER category 1 site.

For non-forest ecosystems (grasslands, heathlands, sparsely vegetated habitats, wetlands, and agricultural habitats), gaseous concentrations of NH_3 and NO_2 [optionally HNO_3 , HONO] and aerosol concentrations of NH_4^+ and NO_3^- , either diffuse or passive samplers can be used together with inferential models. It is also allowed to use different samplers to accommodate alignment with existing national and international monitoring. However, it should be guaranteed that both the samplers and the applied procedure, comply with additional measurements that are conducted for reference such as the methods established for the EU Ambient Air Quality Directive or EMEP (2001).

For forest ecosystems, dry deposition of N is estimated using open field deposition measurements (see SOATM_103) combined with canopy throughfall deposition samplers and canopy budget models following the ICP Forests manual (Clarke et al. 2022). Throughfall contains bulk, leached, and dry-deposited adsorbed ions. Together with stemflow, throughfall provides an estimate of deposition to the forest floor.

Table 2: SOATM_108 PRIME method: raw data and data products to be analysed. Optional parameters are given in brackets.

Site category	1
Raw data	Open field: NH_3 , NO_2 [HNO_3 , HONO] gaseous concentrations ($\mu\text{g m}^{-3}$); NH_4^+ , NO_3^- , NO_2^- aerosol concentrations ($\mu\text{g m}^{-3}$). Forest: Amount of throughfall (mm); Na^+ , NH_4^+ , Cl^- , NO_3^- [N_{total}] concentrations (mg L^{-1}).
Data products	Open field: NH_4^+ [NO_3^-] dry deposition from the inferential model. Forest: Dry deposition of N components from the canopy budget model.

Table 3: Mandatory parameters to be analysed in throughfall deposition (N_{total} : total nitrogen). Optional parameters are given in brackets.

Sample type	Mandatory [Optional]	Comments
Throughfall deposition	Amount of throughfall $\text{Na}^+, \text{NH}_4^+$ $\text{Cl}^-, \text{NO}_3^-$ $[N_{\text{total}}]$	This variable is essential for the determination of fluxes. It must be measured as accurately as possible. To check for contamination due to bird droppings, either PO_4^{3-} or P_{total} can be measured. To calculate organic phosphorus, both parameters have to be measured. NO_2^- may indicate pollen-driven NO_3^- reduction during spring. N_{total} is not mandatory for throughfall deposition, but is highly recommended.
Denuder/Passive sampler	NH_3, NO_2 [$\text{HNO}_3, \text{HONO}$] [$\text{NH}_4^+, \text{NO}_3^-, \text{NO}_2^-$] NH_4^+ [NO_3^-]	Gaseous concentrations. Aerosols (e.g. Delta System). Deposition result from inferential model.

3.2 Diffusion (denuder) sampler for NO_2 and NH_3 concentration in open fields

So-called denuders are coated diffusion separators. These are described, for example, in a guideline issued by the Association of German Engineers (VDI) (VDI 2012). They consist of tubes (usually made of glass) coated with a suitable material (sorbent) through which the air flows laminar. The gaseous compounds react with this sorbent. The dissolution time is between one hour and one month. After sampling, this sorbent is removed and analysed by ion chromatography. The concentration of N compounds can be calculated with a known flow rate through the denuder. Note, that EMEP has a standard protocol, too (Tang and Sutton 2007).

The Radiello-brand sampler, used e.g. by the Ammonia concentration and deposition network AMoN (NADP, US), is a passive device for measuring atmospheric ammonia. It is a simple diffusion-type sampler with no moving parts. It works on diffusion theory, where ammonia is sorbed on the interior surface. This induces a concentration gradient from the outside of the sampler to the inside of the sampler. Phosphoric acid is impregnated on the interior cartridge. This cartridge is placed inside the porous outer body, which provides a predictable diffusion distance and a reproducible diffusion rate of ammonia gas to the interior sorbent. For analysis, the sampler is returned to the laboratory, where the cartridges are removed, and the ammonia (as NH_4^+) is removed by sonication in deionized water. Laboratory analysis for ammonium is then accomplished by Flow Injection Analysis (FIA).

3.3 Passive sampler for NO_2 and NH_3 concentration in open fields

Another comparatively simple method is passive samplers, i.e. small permeable tubes filled with a suitable sorbent. NO_2 and NH_3 diffuses into this tube and reacts with the sorbent. After exposure, the contents are analysed by ion chromatography. For NH_3 , there is a sampling standard (CEN 2020) including several passive sampling methodologies. See also the ICP Forests protocol for passive sampling of NO_2 and NH_3 compounds (Schaub et al. 2020). The measurement period is one week to one month.

3.4 Inferential models

Dry deposition can be estimated from measured atmospheric gaseous concentration (taken from the above described methods), using various assumptions regarding transfer rates through the air and the vegetation. A number of inferential models are available (Flechard et al. 2011; Massad et al. 2010), which have to be cited in the metadata including its parameterization.

3.5 Dry deposition in forests using the canopy budget model

We follow the ICP Forests manual (Clarke et al. 2022) and merely provide an overview here. In order to estimate dry deposition in forests using a canopy budget model, open field deposition has to be known (see SOATM_103, Atmospheric deposition in precipitation) and throughfall deposition beneath the canopy. Throughfall contains bulk, leached, and dry deposition-adsorbed ions. Contributions from occult deposition are included. Together with stemflow, throughfall gives an estimate of the deposition to the forest floor. Like bulk deposition, it is relatively cheap, simple and low-maintenance. Throughfall measurements should be made in such a way that the results are representative for the plot area and should provide information on the coefficient of spatial variation by parameter. This means that a sufficiently large number of collectors should be used and the collectors should be placed in such a way that the variation is covered. Please note that in order to be able to apply a canopy budget model, an ion other than NH_4^+ or NO_3^- (Cl^- , Na^+) has to be measured in open field and in the canopy throughfall.

Note that these kinds of models have recently been criticised since a substantial part of the NO_3^- -reaching the throughfall sampler may stem from canopy nitrification (Guerrieri et al. 2024). Scientific findings in the future may change the perception of canopy budget models.

3.6 Measurement design

3.6.1 Diffuse and passive samplers in open field

When using Delta System denuders please follow Tang and Sutton (2007). The Radiello sampler shelter consists of an inverted plastic shelter permanently fastened to an aluminum u-channel mounting bracket. The shelter is erected such that the lower edge is two meters above surrounding surfaces. See also Schaub et al. (2020) for design aspects.

Throughfall collectors may be either funnels or gutters. We recommend using the same collectors as in SOATM_103. The advantage of using funnels of the same type as for bulk deposition in precipitation sampling is that this makes comparison between bulk deposition and throughfall easier, as effects caused by type of sampler will be minimised. Gutters have the advantage that they integrate over a larger canopy gradient than funnels. In general, the number and location of collectors is more important than sampler type.

3.6.2 Spatial design – Canopy throughfall deposition in forest

Number of throughfall sensors to be used: A throughfall collector samples only the small area where it is placed. In order to take into account the large local variations in throughfall deposition in a forest stand, a sufficiently large number of collectors must be used. Table 2 in the ICP Forests Manual (Clarke et al. 2022) presents the minimum number of collectors (funnels of 100-600 cm²) to be used on sample areas up to 2500 m² (minimum 500 m²) and details about deriving the number of collectors for the plots. The number of collectors is dependent on the forest type and increases with increasing heterogeneity (due to e.g. species mixture, stand density, nearness to forest edges, precipitation types etc.). If gutters are used, the number and length of gutters must be sufficient to cover the variability of the stand deposition. Far fewer scientific studies exist for gutters and therefore no guidelines can be given here, which hints at the necessity of local studies.

Spatial distribution of throughfall collectors: The collectors should be spatially representative of the area of the whole plot (and not only the sub-plot). It is necessary to assess the spatial distribution of the collectors in connection with the number of collectors to be used on a given study area.

It is therefore recommended that the spatial representativity of throughfall deposition (and not concentration) will be checked for each plot for a minimum of one year (depending on the period covered by rainfall) with a high number of collectors (e.g. 30-40). On plots on which precipitation in the form of snow contributes to more than 20% of the annual throughfall, the spatial arrangement study should be done for both snow and rain periods, i.e. during the vegetation and winter periods. Snow type and quality is quite different during the winter and the frequency of the different snow types depends on latitude and longitude. Few scientific studies on the variability of snow under the forest cover exist, which hints to this necessity of local studies.

Neither a systematic nor a random approach can be considered as the only solution: both are valid. A systematic distribution is one that is ordered and regular (see below for an example). A random distribution is not the same as subjective: if a random design is chosen, it has to be random in a statistical sense, i.e. every part of the plot has an equal chance of being selected. Systematic or random distribution can be used, or even better a combination of both. A combination of systematic and random distributions has the big advantage of covering the whole plot used for deposition monitoring. Thus, the plot area is divided in quadrates of equal sizes (length to be adapted to the size of the study area). Within each quadrate, the sample points are chosen randomly. Distribution of collectors should avoid systematic errors, e.g. placing of collectors equidistant to the stems of neighbouring trees.

3.6.3 Temporal resolution

The temporal resolution of the PRIME method is determined by the sampling approach and differs between measurement types.

Diffusion (denuder) and passive samplers in open fields The exposure period for diffusion (denuder) and passive samplers ranges from one week to one month. For denuders, the dissolution time may be as short as one hour, depending on the specific device and application. The selection of exposure duration should ensure that the measured concentrations are representative of the monitoring period while maintaining detection limits for the target compounds. Alignment with national and international monitoring programmes should be considered where applicable.

Canopy throughfall deposition in forests Throughfall deposition is measured at the same temporal resolution as the precipitation measurements specified in SOATM_103 (Atmospheric deposition in precipitation). The collection interval should be event-based or weekly at minimum, consistent with the bulk deposition sampling scheme, to allow for accurate volume-weighted concentration calculations.

3.7 Calibration

The calibration of diffuse and passive samplers was performed according to the manufacturers' recommendations for each respective sampler type

4 Data and metadata format

4.1 Data processing

4.1.1 Air concentration

Data processing is carried out following the recommendations of Schaub et al. (2020).

4.1.2 Throughfall deposition

Simple guidelines for calculations are given in Annex 3 of Clarke et al. (2022). All concentration means should be volume weighted. The precipitation amount obtained by the sampling collector is used to calculate the deposition at the site. It is recommended to compare with the results from the meteorological standard gauge. If the difference is significant, the selection of collector must be reconsidered. Guidelines for interpretation of throughfall data are given in Annex 6 of Clarke et al. (2022). Data processing and reporting of throughfall deposition is in accordance with the procedure established for SOATM_103.

4.1.3 Canopy budget model

Clarke et al. (2022) provide an overview in Annex 1 of the ICP Forests Manual. Due to the complexity and number of available models, a centralized calculation using one harmonized procedure may be considered.

4.2 Reporting format

Reporting is conducted in accordance with the rules and conventions specified in Peterseil and Geiger (2020)¹ regarding file naming, file formats, and metadata scope.

Metadata specific for SOATM_108 are given in Table ??.

Table 4: Metadata specific to SOATM_108

Metadata field	Description
Location data	Latitude and longitude (decimal degrees, 1 m resolution), altitude (1 m resolution), and DEIMS-SDR link (site and observation location)
Time stamp	Date and time in UTC
Data structure	Description of the data structure (e.g., header of a comma-separated values file)
Denuder/Passive sampler type	Type of device used for measuring N-compound concentrations
Large-scale deposition model	Model type, version, and date of retrieval (e.g., EMEP MSC-W version ##; 2024-11-01)
Inferential model parameterization	Model and parameterization used for estimating dry deposition
Contact person	Name and email address

¹Document is currently under revision.

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