

## Chapter 2

# Progress in Monitoring and Modelling Estimates of Nitrogen Deposition at Local, Regional and Global Scales

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**Abstract** This chapter discusses the status and progress of activities around the world to measure and model dry and wet deposition of reactive nitrogen ( $N_r$ ), i.e. the final removal processes from the atmosphere, at the local, regional and global scales. It gives an overview of present status and developments in networks and techniques for measuring deposition of  $N_r$ . We describe recent developments in the modelling of emissions and deposition, and finish by giving research and policy recommendations regarding N-deposition measurement and modelling, including the need for;

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- an increase in the number of regional-scale, long-term monitoring sites for the routine measurement/estimation of wet and particularly dry deposition worldwide;
- an increase in the number of N species routinely measured, especially dissolved organic N (DON), ammonia (NH<sub>3</sub>) and nitrogen dioxide (NO<sub>2</sub>);
- global and regional models to improve their estimation of dry deposition and their resolution, especially in situations with complex topography.

**Keywords** Atmospheric deposition • Emissions • Measurement • Modelling • Oxidized and reduced deposition • Wet and dry deposition

## 2.1 Introduction

Reactive nitrogen (N<sub>r</sub>) compounds in the oxidized form (NO<sub>y</sub>) and the reduced form (NH<sub>x</sub>) play a central role in the chemistry of the atmosphere as well as in the functioning of marine, freshwater and terrestrial ecosystems. There is ample evidence that increasing human activities seriously disturb the natural nitrogen (N) cycle. Reactive nitrogen enters the environment through a number of processes related to fertilization, waste discharge and atmospheric emissions, transport and deposition.

Here we discuss progress pertinent to measurement and modelling of dry and wet deposition of N<sub>p</sub>, i.e. the final removal processes from the atmosphere, at the local, regional and global scales. We cover (a) present status and developments in networks and techniques for measuring deposition of N<sub>p</sub>, (b) recent developments in the modelling of emissions and deposition, and (c) research and policy recommendations regarding N-deposition.

## 2.2 Measurements

### 2.2.1 Introduction

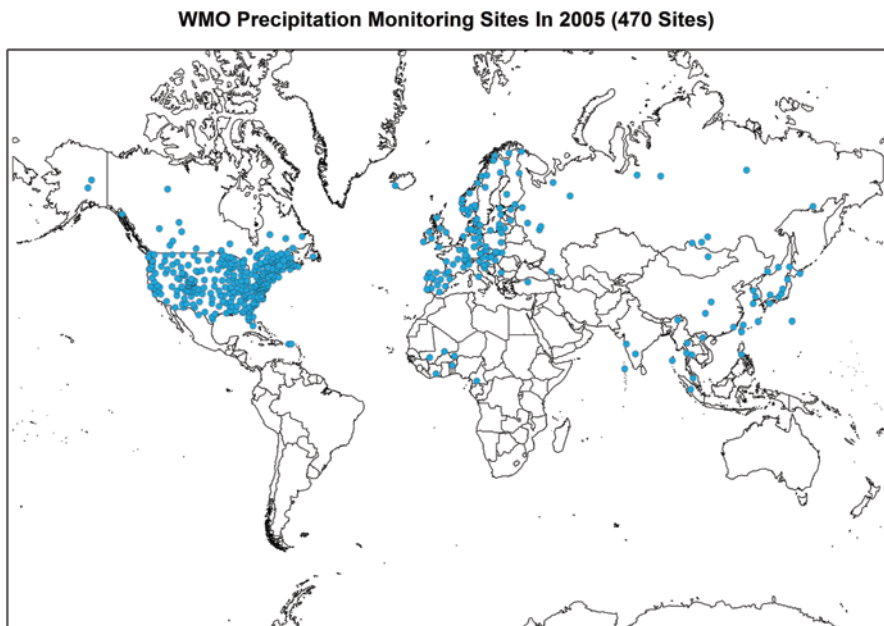
The term dry deposition applies to all removal processes of gases and aerosols at the earth's surfaces; this process does not necessarily have to be 'dry', in fact the removal of gases like SO<sub>2</sub> is rather efficient to wetted surfaces or ocean water. The research of dry deposition processes has been stimulated by the acid rain problem in the USA, Europe and Asia. Many different techniques have been used to measure dry deposition fluxes such as gradient methods, eddy correlation techniques, chambers or the use of artificial surfaces. Whereas these measurements provided new insights into the processes playing a role for removal of air pollutants by dry deposition, they were by no means routine determinations, and required a large effort

in terms of equipment, labor and interpretation. The accuracy of the measurements was in the best case of the order of  $\pm 30\%$ . The validity of the measured fluxes for a larger region (the so called 'fetch') was in most cases rather limited. Aircraft measurements provided a new method for estimating dry deposition fluxes, mainly by means of eddy correlation techniques. However these measurements are generally very expensive, and the sampling period limited. The geographical coverage was obviously much better than the 'local' measurements mentioned previously and in addition showed the complex behavior of boundary layer dynamics and the resulting effect on dry deposition. Measurements are generally presented as dry deposition velocities [cm/s] or as surface resistances, which is approximately reciprocal of the dry deposition velocity.

Wet deposition refers to the removal of gases and aerosols by scavenging in clouds (uptake in cloud droplets/ice crystals, formation and sedimentation of rain) and precipitation scavenging (falling rain droplets and frozen hydrometeors interacting with particles and gases). Measurements of wet deposition are almost entirely made by collection and analysis of rain and snow samples. Whereas in the past frequently bulk samplers were utilized, which measured a substantial and largely unquantified amount of dry deposition, nowadays mostly wet-only samplers are employed, opening and closing the sampler at the beginning and end of rainfall events.

### ***2.2.2 Worldwide Networks of Wet Deposition***

Continuous large-scale measurements of wet deposition have been made since the 1970s. Since then, many international, national, and sub-national monitoring networks/programs have been operated and, in some cases, expanded, reduced and/or closed. The major long-term, large scale, regionally-representative monitoring networks that exist at this time include the Canadian Air and Precipitation Monitoring Network (CAPMoN) and related Canadian provincial networks, the Acid Deposition Monitoring Network in East Asia (EANET), the European Monitoring and Evaluation Program (EMEP), the International Global Atmospheric Chemistry (IGAC) Program's Deposition of Biogeochemically Important Trace Species Project (DEBITS) in Africa (IDAF), Asia (CAD and EANET) and South America (LBA), the United States National Atmospheric Deposition Program (NADP), and the World Meteorological Organization Global Atmosphere Watch Precipitation Chemistry Program (GAW). A number of other national and sub-national networks also operate in countries such as Russia, China, Korea, Taiwan, and India. These networks typically measure the concentrations of the following major anions and cations in precipitation:  $\text{SO}_4^{2-}$ ,  $\text{NO}_3^-$ ,  $\text{Cl}^-$ ,  $\text{H}^+$ ,  $\text{NH}_4^+$ ,  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Na}^+$  and  $\text{K}^+$  (and in some cases, organic acids and phosphorus) as well as precipitation amounts. Figure 2.1 shows the regional sites of the aforementioned major networks that reported data in 2005.

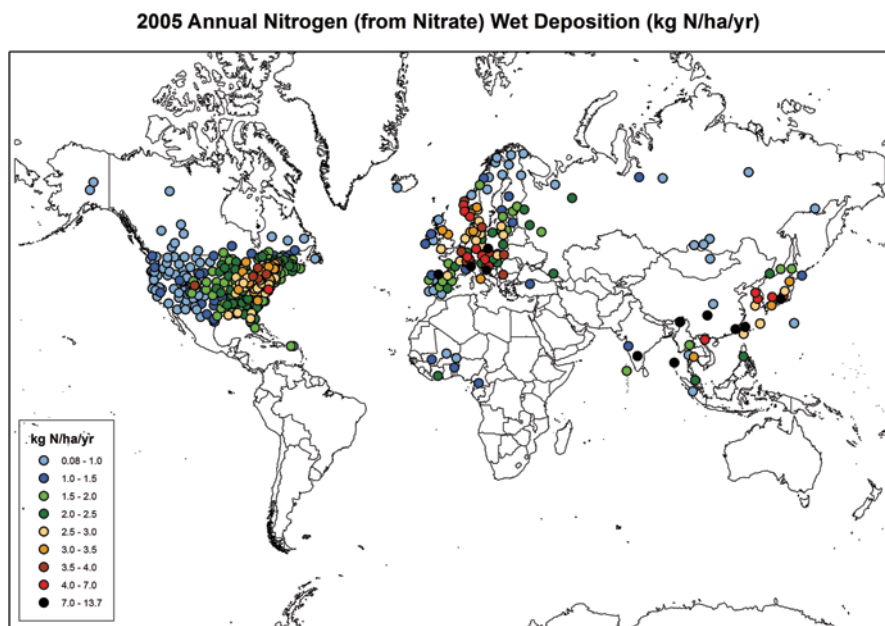


**Fig. 2.1** Regional-scale wet deposition monitoring sites that reported data in 2005

The scientific objectives of wet deposition monitoring networks vary depending on the country and/or the specific scientific program, but most networks focus on the following: defining the spatial patterns of ion wet deposition, investigating the long term trends of ions in precipitation, evaluating chemical transport models, calculating critical loads, and investigating atmospheric processes. The World Meteorological Organization (WMO), through its Scientific Advisory Group for Precipitation Chemistry is currently preparing a scientific assessment of global deposition and, to that end, has integrated and synthesized data from most of the foregoing networks. An example of that effort, a preliminary global pattern of  $\text{N-NO}_3^-$  wet deposition in 2005, is shown in Fig. 2.2.

Over the last decade, the number of wet deposition monitoring sites has generally increased in Asia, Eastern Europe and the USA. Unfortunately, large areas of the world still have few if any measurements, namely, South America, Africa, Australia, Oceania, western/northern Canada, the oceans, and the polar regions.

The major problems with wet deposition measurements, beyond the paucity of measurement sites, are poor laboratory performance and inaccurate field measurements. The World Meteorological Organization is addressing these problems through the long-term operation of semi-annual laboratory inter-comparison studies and the publication of a manual for the proper measurement of wet deposition (WMO 2004). Nevertheless, these problems persist in many countries.

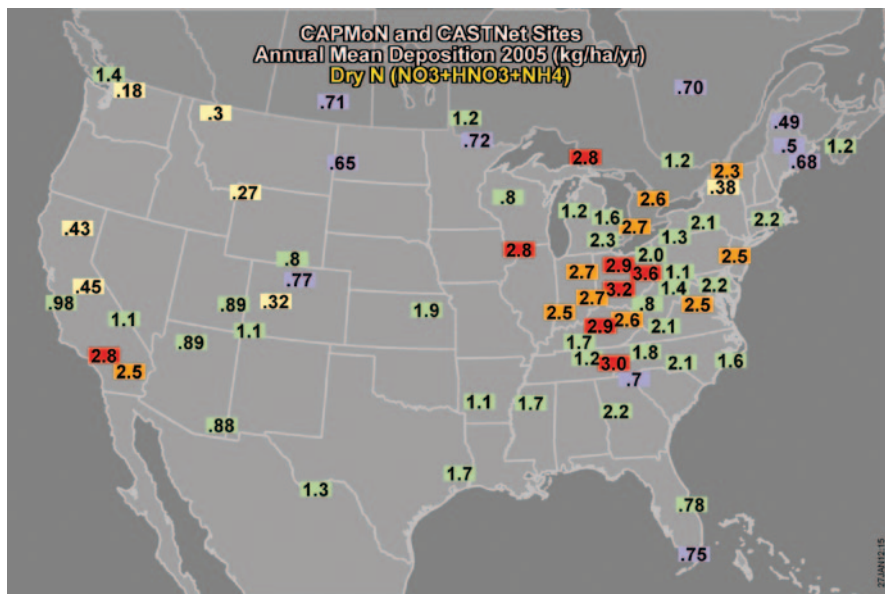


**Fig. 2.2** Preliminary 3-year average annual deposition of wet deposition of  $\text{NO}_3^-$  as N (in  $\text{kg N ha}^{-1} \text{ year}^{-1}$ ) for the period 2005. Some sites do not have all 3 years of data

### 2.2.3 Dry Deposition Measurement Networks

Dry deposition is not measured directly by large-scale monitoring networks because of the requirement for sophisticated instrumentation and methods. Instead, networks measure ambient gas and particle concentrations and model the associated dry deposition velocities. This method, which ultimately requires multiplying the ambient concentrations by the modelled dry deposition velocities, is called the *inferential technique*. Only two major networks currently make regionally-representative routine inferential estimates of dry deposition fluxes, namely, the United States Clean Air Status and Trends Network (CASTNET) and the Canadian Air and Precipitation Monitoring Network (CAPMoN). The former currently comprises 86 sites in the USA ([www.epa.gov/castnet/docs/CASTNET\\_factsheet\\_2007.pdf](http://www.epa.gov/castnet/docs/CASTNET_factsheet_2007.pdf)) and the latter 15 sites in Canada ([www.msc.ec.gc.ca/capmon/index\\_e.cfm](http://www.msc.ec.gc.ca/capmon/index_e.cfm)). An inferential model is currently under development for Africa under the IDAF (IGAC/DEBITS/AFRICA) project of the International Global Atmospheric Chemistry/Deposition of Biogeochemically Important Trace Species (IGAC/DEBITS) program (<http://medias.obs-mip.fr/idaf>).

Unfortunately, neither the US nor Canadian networks measure all of the major oxidized and  $\text{N}_r$  species needed to estimate the total atmospheric loading of N. Both



**Fig. 2.3** Estimated 3-year-average dry deposition fluxes of nitrogen ( $\text{N ha}^{-1}\text{year}^{-1}$ ) from particle- $\text{NO}_3^-$ , particle- $\text{NH}_4^+$ , and gaseous  $\text{HNO}_3$  based on data from the United States Clean Air Status and Trends Network and the Canadian Air and Precipitation Monitoring Network

networks measure particle- $\text{NO}_3^-$ , particle- $\text{NH}_4^+$ , and gaseous  $\text{HNO}_3$ , but not  $\text{NO}$ ,  $\text{NO}_2$ , PAN,  $\text{NH}_3$  or organo-nitrates—some of which are important contributors to dry deposition. Thus, the dry deposition fluxes (and wet + dry deposition fluxes) of N estimated by these two networks are thought to be quite conservative.

An illustration of the CASTNET and CAPMoN dry deposition monitoring sites and their estimated 2005–2007 annual average dry deposition fluxes of N is shown in Fig. 2.3. As mentioned above, these estimates are based only on particle- $\text{NO}_3^-$ , particle- $\text{NH}_4^+$ , and gaseous  $\text{HNO}_3$  fluxes and are missing the other potentially-important nitrogen species, most notably  $\text{NH}_3$  and  $\text{NO}_2$ . From Fig. 2.3, one can see that dry deposition fluxes are higher in eastern North America than in western North America (with the exception of southern California), which is a reflection of the spatial distribution of  $\text{NO}_x$  emissions in North America.

Globally, the number of sites that provide inferential dry deposition estimates is insufficient, with few estimates in South America, Africa, Australia, Oceania, northern Canada, Asia, the oceans and the polar regions. Additionally, most ambient air monitoring networks do not measure all of the N compounds necessary to determine the total atmospheric loading of N. Even the two existing North American inferential dry deposition networks, CASTNET and CAPMoN, have known measurement uncertainties due to the volatilization of particle- $\text{NH}_4\text{NO}_3$ , and large uncertainties in the flux estimates due to differences in their respective inferential models. As a result, dry deposition monitoring on a global basis is inadequate.

There needs to be a commitment in the measurement community to developing routine network measurement systems that provide the data required to assess dry deposition on a regional and global basis.

In the appendix to this chapter we give a short overview of some of the networks, Table 2.1 lists some of the issues that were identified for these networks.

### ***2.2.4 Use of Deposition Measurements***

How are the network measurements being used? Using statistical techniques like Kriging or Optimal Interpolation, the measurements can be directly interpolated to larger geographical regions. The applicability of such methods depends on the presence of sufficient data that are at a short-enough-distance to be correlated with each other. They can be combined with meteorological modelling, for instance to derive dry deposition fluxes. They can be used as independent data sets to verify atmospheric models, as will be elaborated in Sect. 2.3 (this chapter), the measurements can be assimilated in models to achieve an optimized agreement between model and measurements space- a process known as data-assimilation. An overarching theme in all techniques is the representativeness of point measurements for larger scales.

## **2.3 Modelling**

### ***2.3.1 Models***

There is a large range of models available to describe air pollution chemistry and transport. These models range from describing near-point source dispersion to global transport processes- the choice of model depends on the issue and the availability of input data.

Many processes are parameterized in models, and consequently the models can only provide a limited representation of reality. The models in use to describe N emissions, chemistry and transport, can be typically separated into plume models, useful at say farm-scale, Lagrangian and trajectory models tracking long range transport of pollution plumes, and Eulerian grid-point models. While plume models continue to be useful in a regulatory framework, today overwhelmingly Eulerian models are used to describe ozone and aerosol chemistry, and are also providing estimates of the deposition of N components. Global models are increasingly used for providing maps of reduced and oxidized N. Resolutions of global models are currently ranging from  $1^\circ \times 1^\circ$  to  $4^\circ \times 5^\circ$  lat-lon, and expected to improve to  $0.5^\circ \times 0.5^\circ$  in the coming years. The global models obviously cannot cover many of the regional deposition details; nevertheless a recent comparison of Dentener et al. (2006) showed good comparison of 21 global models with measurements in North America and

Table 2.1 Issues associated with regional nitrogen deposition monitoring networks

North America: CASTNET/ NADP/CAPMoN	Europe (EMEP)	South Asia (CAD)	South East/East Asia (EANET)	Africa (DEBITS/IDAF)
<p><i>Wet deposition:</i> Incomplete closure of N budget; no DON Too few measurement sites in certain areas</p> <p><i>Dry deposition:</i> Not all gases being measured rou- tinely e.g. NH<sub>3</sub>, NO<sub>x</sub>, PAN and organo-nitrates are missing</p> <p>Too few measurement sites</p>	<p>Measurements performed on country basis, dif- ferences in measure- ment quality and sampling protocols?</p> <p>In some regions very few measurements (South- ern Europe)</p> <p>Measurements for N budget incomplete</p>	<p>Data quality: delay in analysis leading to underestimate of NH<sub>4</sub> and NO<sub>3</sub></p> <p>Lack of rural sites, and long term measurements Lack of quality controlled data</p> <p>Difficulties estimating deposition of NO<sub>x</sub> and NH<sub>3</sub> gases</p> <p>High ammonia specific for India</p>	<p>Currently focus on acid deposition rather than N deposition. DON is not measured. Insufficient sites in China</p> <p>Organic nitrogen species (e.g. PAN and organo-nitrates) are missing In some sites especially in China, dry N deposition data is missing Insufficient sites in rural and remote places. More sites needed in China</p> <p>Regional specific models need to estimate the rates of dry deposition</p>	<p>Eight stations covering con- tinental scale; representing major ecosystems Wet deposition budget incom- plete (no DON) Dry deposition complete NO<sub>2</sub> +HNO<sub>3</sub>+NH<sub>3</sub>+pNO<sub>3</sub><sup>-</sup>+pNH<sub>4</sub> 4. Dry deposition of gases combining long-term passive samplers measurements and site-specific deposition veloc- ities: large uncertainty. Bulk measurements for particles</p> <p>All the African Sites are located in non perturbed rural regions Lack of urban sites to measure hot spots sources and associ- ated deposition (planned)</p> <p>Nitrogen deposition in coastal areas should be emphasized especially in east China</p> <p>Development of an inferential model for African ecosystems</p>
<p>Siting criteria require placement of the sites away from large sources. Thus, the network will miss hot spots and estimates of deposition budgets based on interpolation of sparse sites will be biased low</p> <p>At some sites, violation of theoret- ical siting requirements for dry deposition monitoring, e.g., locating sites in complex terrain</p> <p>Lack of comparability between the US and Canadian inferential dry deposition estimates</p>				



Europe, reasonable performance in South East Asia, but larger problems in Africa, South Asia, and South America.

The spatial domain and resolution of regional models has been steadily improving. In the USA and Europe the typical resolution of continental models has decreased from 36 km to 12 km grid sizes. However, 12 km is still too coarse for critical load modelling in complex terrain (hills, valleys), where much of the critical load work in e.g. the USA is focused. Throughfall measurements suggest that there is a high degree of deposition variability within a grid in complex terrain that is important to critical loads (Weathers et al. 2006). These problems are associated with the inability of models to capture orographic effects on rainfall amounts, or effects of terrain and land cover type on dry deposition. Parameterizations for this subgrid variability would be helpful.

Also, even in flat terrain, dry deposition will depend on land cover type. It is essential that methods be developed to account for this variability rather than use a single number per grid. Efforts are being made to make dry deposition land-use specific within a grid.

A similar problem occurs in Europe, and probably also elsewhere, where patches of natural land are included in farmland. Current global and regional models should address this sub-grid phenomenon.

It is worth mentioning here, that models describing  $\text{NO}_x$  and  $\text{NH}_x$  chemistry and deposition, are almost always part of larger models describing photochemistry and aerosol dispersion processes in general, and not necessarily focusing on correctly describing deposition processes. Increasingly, models now combine their aerosol and photochemistry modules.

### **2.3.2 Land Use Databases**

As mentioned above models use land cover databases to describe a number physical processes (e.g. albedo, surface roughness), but also the parameters needed to perform calculations of dry deposition. These databases are provided on a relatively detailed resolution by the USGS and the updated NLCD (National Land Cover Data base) in the USA, or CORINE (Coordination of information on the environment) in Europe. Examples of relatively high resolution global land cover database include the GLC2000 land cover database, MODIS land cover, and the IGBP. A recent comparison of 3 global land cover databases (Herold et al. 2008) shows large differences in these databases arising from the use of different remote sensing instruments, interpretation methods, and perhaps most importantly different classification methods, that may regionally differ. Especially among classes of mixed vegetation there are large differences. These uncertainties are propagated into atmospheric models, and often it is not clear what land-cover database is actually included in the various model results. Very recently, a global land-cover database from the MERIS (Envisat's Medium Resolution Imaging Spectrometer) at 300 m resolution has become available. The high spatial resolution should help to more unambiguously attribute

land-cover classes—with less need to define ‘mixed’ classes. A recurring theme in the land-cover and land-use databases is the adequacy of the chosen classification to accurately address the users need. We mention here that many atmospheric models work with often outdated landcover databases, possibly leading to large inconsistencies.

### 2.3.3 Emissions

Because photochemistry and aerosol physics are involved, description of N deposition, emissions for local, regional and global models requires inclusion of  $\text{NO}_x$ , VOC,  $\text{NH}_3$  and  $\text{SO}_x$  emissions at a minimum. Except for power plant  $\text{SO}_2$  and  $\text{NO}_x$  emissions, which can be measured at the stack, emissions are estimated using models and emission factors multiplied by activity indicators. Then these emissions must be geographically located, which introduces additional uncertainty.  $\text{SO}_x$  emissions are mostly from power plants, and industry.  $\text{NO}_x$  emissions involve many sectors, including on-road and off-road vehicles, area sources, and industrial and power plant stacks.  $\text{NH}_3$  emissions are mostly from animal operations and fertilizer application (agriculture). Assessments of emission uncertainty for the USA suggest  $\text{SO}_x$  emissions are the most certain, due to the use of stack Continuous Emissions Monitors (CEMs).  $\text{NO}_x$  emissions have an intermediate level of uncertainty and  $\text{NH}_x$  emissions are the least certain (Dennis et al. 2008). This ranking is corroborated by comparisons of the regional models in the USA against NADP wet deposition data. Similarly, in Europe country total emissions are relatively well known, and detailed spatial desegregation (gridding) is available for some countries. EMEP interprets national reports on emissions, and provides an expert based emission inventory on a 50 km scale. Elsewhere in the world inventories have been created on a project-basis (i.e. TRACE-P), but there are generally no officially endorsed gridded emission databases available. There are attempts to provide compilations of gridded datasets on global and regional scales by the IGAC endorsed GEIA (Global Emissions Inventory Activity; <http://www.geiacenter.org>). Consistent inventories of pollutant and greenhouse gas emissions are provided by the EDGAR team ([edgar.jrc.ec.europa.eu/index.php](http://edgar.jrc.ec.europa.eu/index.php)). EDGAR4 will contain global high resolution 10 km by 10 km data for the major pollutant emissions.

Emission projections (e.g. the new projections in the context of the IPCC AR5 report) indicate that air pollution control strategies may lead to stabilization or even a decrease of  $\text{NO}_y$  depositions worldwide. Mitigation strategies addressing climate change may also lead to reduced  $\text{NO}_y$  deposition. Much less attention is given to  $\text{NH}_3$  emissions, and most scenarios indicate further growth of  $\text{NH}_3$  emissions.

## 2.4 Key Recent Developments

Key recent developments are attempts to bring together datasets on wet and dry deposition at the global scale that are endorsed by international programs (e.g., IGBP and WMO). Deposition data availability in Asia is rapidly improving due to the operation of the EANET network and many national networks. First steps to set-up consolidated measurement capacity in Africa are encouraging. From the analytical point of view, the recent measurements of organic N components have triggered research to determine the origin and importance of these components, with literature estimates as high as 30% of the wet N deposition budget.

Models are improving. There is a tendency for global models to go to finer resolutions, and regional models are expanding their model domain, as well as improving resolutions. This development is fostered by a continuing increase of computing capacity, and improved skills of numerical weather prediction models, from the global to the regional scale. Nevertheless, errors in emission inventories and in the meteorological model predictions are still a significant issue for modelling of N deposition and critical loads. Improvements of the physics in meteorological models are still needed. For instance careful analysis of throughfall measurements suggest cloud deposition can be very important above certain elevations. The models typically do not include cloud droplet deposition (also known as 'occult' deposition).

Regional models in the USA have been used successfully to establish top down constraints on  $\text{NH}_3$  emissions and estimate the seasonality of the  $\text{NH}_3$  emissions (Gilliland et al. 2003, 2006). With the top down estimates the model predictions of the gas-particle partitioning of the inorganic species significantly improved. Of course, the inverse results subsume and are influenced by any model errors. Kononov et al. (2006) used satellite information to derive NO emissions over Europe, and similarly. Kurokawa et al. (2009) obtain NO emissions over East China.

Models are increasingly using the possibility to ingest large sets of observations, a process called data assimilation, and adapted from the numerical weather prediction community. Relevant for N, the suite of  $\text{NO}_2$  measurements available from GOME, Sciamachy, OMI, GOME-2 satellites, is increasingly used. Important information on trends can be obtained from satellite information (Richter et al. 2005). While the process understanding does not necessarily improve by data assimilation, it certainly improves the model predictions of the related  $\text{NO}_y$  deposition. Very recently, also the first satellite based  $\text{NH}_3$  measurements were reported, but it is unlikely that the current IR satellite instruments will provide reliable measurements globally.

Finally, more detailed emission inventories are being compiled, either by combining national level detailed inventories, but also high resolution bottom-up inventories like EDGAR4, targeting at global resolutions of  $0.1^\circ \times 0.1^\circ$ .

## 2.5 Recommendations

- **Measurement gaps**
  - The deposition measurement community has long recognized that there are too few wet and dry deposition measurement sites operating worldwide (WMO 2008). Those monitoring sites that do exist generally do not measure the complete suite of N species needed to close the atmospheric N budget. The problem is worse in substantial parts of the developing world.
- **Measurement recommendations**
  - Increase the number of regional-scale, long-term monitoring sites for the routine measurement/estimation of wet and dry deposition worldwide.
  - Continue and increase capacity building for measuring wet and dry deposition in the developing world.
  - Increase the number of N species routinely measured in wet and dry deposition monitoring networks to close the atmospheric N budget, most notably DON, NH<sub>3</sub> and NO<sub>2</sub>.
- **Modelling gaps**
  - Regional and global model representation of wet deposition is reasonable in Europe and the USA but still very uncertain in other parts of the world. Modelled dry deposition fluxes are very uncertain, and can seldom be compared to measurements, due to many factors including incompleteness of observations, uncertainties in chemistry schemes, and sparseness of measurements.
- **Modelling recommendations**
  - Global as well as regional models need to improve their resolutions, especially in situations with complex orography. All models still have substantial uncertainties in their representation of the hydrological cycle (rain, snow). It is recommended that models closely follow improvements in model parameterization coming from the meteorological community.
  - Relatively little attention is given to model representations of dry deposition. Use of the best available land-use datasets, and closer linkage to meteorological model predictions of critical parameters and to observations of parameters to estimate dry deposition fluxes is important. More measurements are essential to improve the models, including carefully designed special field campaigns.
  - Deposition processes vary on several timescales: from daily fluctuations to seasonal and inter-annual variations. The models' performance should be tested on all timescales- e.g. at least the seasonal changes with variations in landcover (e.g. snow, vegetation) and hydrology (monsoon) should be represented well in the models.
  - Since there is a serious lack of wet and dry deposition measurements, models need to be verified and improved using as much as possible alternative datasets, such as ambient concentrations, dedicated field study data and model intercomparisons. Promising datasets are becoming available from satellites,

but more work needs to be done to consistently combine the model and measurement frameworks.

- New emission data sets are becoming available; and should be used. However, these datasets should be checked as much as possible using knowledge in countries and regions under consideration ('ground-truthing'), as well as with top-down techniques.

For further recommendations on the monitoring and modeling of N deposition see the working group report (Aas et al. 2014, Chap. 48, this volume).

## Appendix: Overview of Networks

### *DEBITS/IDAF (<http://medias.obs-mip.fr>)*

Under the auspices of the international DEBITS program, with about 25 stations in the tropical belt, the objective of the African IDAF project is to measure wet- and dry-deposition fluxes and identify the relative contribution of natural and anthropogenic source of a number of components. The IDAF project implemented 8 monitoring sites covering the major African ecosystems over West and Central Africa: dry savanna (Niger, Mali, South Africa), wet savanna (Côte d'Ivoire and Benin) and equatorial forest (Cameroon, Congo). Wet deposition is measured by precipitation collectors specially designed for the IDAF network, and all the analysis are quality controlled by the quality assurance and quality control (known as 'QA/QC') inter-comparison WMO programme. Typical values for wet deposition of N components range from 0.9 kg N-NO<sub>3</sub><sup>-</sup> ha<sup>-1</sup> year<sup>-1</sup> and 1.5 kg N-NH<sub>4</sub><sup>+</sup> ha<sup>-1</sup> year<sup>-1</sup> in dry savannas, 1.3 kg N-NO<sub>3</sub><sup>-</sup> ha<sup>-1</sup> year<sup>-1</sup> and 2.9 kg N-NH<sub>4</sub><sup>+</sup> ha<sup>-1</sup> year<sup>-1</sup> in wet savannas and 2 kg N-NO<sub>3</sub><sup>-</sup> ha<sup>-1</sup> year<sup>-1</sup> and 3 kg N-NH<sub>4</sub><sup>+</sup> ha<sup>-1</sup> year<sup>-1</sup> in forests. Dry deposition is estimated using measurements of gaseous and particulate species based on continuous measurements of gaseous concentrations through passive gas sampling (NO<sub>2</sub>, NH<sub>3</sub>, HNO<sub>3</sub>), and on bulk air sampling (ammonium and nitrate particulate content). These concentrations are multiplied by site and species specific dry deposition velocities. A detailed overview of the IDAF network can be made available by C. Galy-Lacaux.

### *EANET ([www.eanet.cc](http://www.eanet.cc))*

The Acid Deposition Monitoring Network in East Asia (EANET) was established in 1998 and the regular phase activities were started in 2001, with the UNEP Regional Resource Centre of Asia and the Pacific (UNEP RRC.AP) in Thailand as the secretariat, and the Acid Deposition and Oxidant Research Center (ADORC) in

Japan as the Network Center. The objectives of the EANET are to create a common understanding on the state of acid deposition problems in East Asia, provide useful inputs for decision making at various levels with the aim of preventing or reducing the adverse impacts on the environment, and promote cooperation among countries (<http://www.eanet.cc/eanet/outline.html>). EANET monitors four environmental items—wet deposition, dry deposition, soil and vegetation, and inland aquatic environment. Currently there are 56/47 wet/dry deposition monitoring sites and 19 ecological monitoring sites from fourteen countries in East Asia. Using common methods, wet acid deposition is estimated by analyzing the rainwater's concentrations of sulphate ( $\text{SO}_4^{2-}$ ) and nitrate ( $\text{NO}_3^-$ ), and dry acid deposition by calculating measured concentrations of sulfur dioxide ( $\text{SO}_2$ ), nitrogen dioxide ( $\text{NO}_2$ ), ozone ( $\text{O}_3$ ) and particulate components (for more details see <http://www.eanet.cc/index.html>).

### ***South Asian Network: Composition of Asian Deposition***

Several initiatives like the CAD (Composition of Asian Deposition) associated with DEBITS, and the Malé Declaration provides a framework for the measurement of rain chemistry and gaseous concentrations. Nevertheless, in India, for example, there is no national deposition network, although there are several individual measurement activities. Recently, Kuhlshrestha et al. (2005) compiled a data set of about 100 stations, of which 50 stations which can be characterized as “rural” and “sub-urban.” Only a few stations operated wet-only measurements.

In the South Asian region, specific studies to monitor N deposition have not been carried out. As part of individual efforts or through limited networks, wet and dry deposition of N has been reported, unfortunately most results are not reliable due to the delay in chemical analysis and improper sample storage. Estimation of nitrate or ammonium needs to be done immediate after sample collection. Moreover, very few publications reveal their quality assurance (QA) procedures, and clearly future network activities will have to address these QA/QC issues. It is worth mentioning here that through CAD, a few groups working on wet and dry deposition studies have been trained for good quality analysis. Good results in a recent EANET inter-comparison exercise are encouraging. More encouragement for QA/QC in measurements in the South Asian region will strengthen the data reliability. More information can be obtained from Umesh C. Kulshrestha.

### ***European EMEP network***

The framework for EMEP (European Monitoring and Evaluation Programme) is provided by the Convention on Long-range Transboundary Air Pollution), ratified by 50 countries. The network ([tarantula.nilu.no/projects/ccc/network/index.html](http://tarantula.nilu.no/projects/ccc/network/index.html)) consists of some 100 operating stations, which cover measurements of acidifying/

eutrophying components, ozone, heavy metals, POPs, VOCs and PM. The stations are not equally distributed over Europe, with very few stations in Southern Europe. Likewise, the quality and completeness of the measurements may differ from country to county. Given the large heterogeneity of land-use and emissions in Europe, it is sometimes difficult to classify stations as truly background, rural, or urban. More information can be obtained from Wenche Aas.

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