Assessment of temporal and spatial characteristics of nitrogen dry deposition in the Phoenix Metropolitan Area

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Introduction and Aims

1. The aim of our study is to answer the question if nitrogen dry deposition represents a significant input to the N mass balance of the CAP ecosystem.
2. Direct measurement of atmospheric deposition rates by national monitoring networks do not currently include sites in urban areas. CAP monitoring currently only samples the coarse particulate component of dryfall. Monitoring of fine particulate and gaseous deposition by NOAA has been only carried out at one undeveloped desert site to the east of the urban area.
3. Regulatory air quality models offer the opportunity of simulating dry deposition fluxes in urban areas with a relatively high spatial resolution (1 km x 1 km), but usually only over a few day period – due to expense in computation time and the lack of emission inventories as well as accurate meteorological information. Dry deposition fluxes can also be calculated by means of diagnostic models which use measured pollutant concentrations and meteorological data at a reference height in the atmosphere as input data. The advantage of this approach is that data are often available on a continuous basis over extended time periods and from sites within urban core areas. However, the main limitation arises from the low density of monitoring stations, which makes it difficult to assess the degree of spatial variation in deposition accurately.
4. In order to determine nitrogen dry deposition fluxes we developed a diagnostic model which includes equations describing the surface energy balance and the ability of the surface to take up matter. Input data are measured airborne pollutant concentrations (NO, NO_2, NO_x) and hourly meteorological variables. Those data are available from 6 air quality monitoring stations operated by the Arizona Department of Environmental Quality and Maricopa County Air Quality Division. The simulated deposition fluxes are representative for an area of about 2 km x 2 km around the monitoring station. Simulation results of diurnal and seasonal characteristics of the deposition fluxes are presented for the year 1998.

Materials and Methods

1. *Model description*: We applied the approach of Hanna & Chang (1992) for the calculation of turbulent energy fluxes over urban areas. The sensible and latent heat fluxes are functions of a moisture availability factor which depends on the land cover fraction of irrigated vegetation *(*Oke 2001, personal communication). The vertical dry deposition flux is modeled by means of the concept of the deposition velocity (Bolin *et al.* 1974) and the difference of the pollutant local mean concentrations at reference height and at the surface. In the calculation of the surface resistance we follow the equations and parameters of Walmsley and Wesely (1995). In order to account for the adaptation of the local vegetation to very high temperatures we replaced the temperature response function of canopy stomatal resistance with the response function suggested by Jarvis (1976). This allows for the parameterization of the temperature thresholds of the opening of the plant's stomata for trees and shrubs in semiarid and arid regions (Larcher 1994). Necessary input data for the model are atmospheric state variables and pollutant concentrations at a reference height (simulated or measured) as well as parameters which describe surface characteristics such as albedo, emissivity and roughness length.

Table 1: Fraction of land cover around the air quality monitoring sites

Site	Urban	Irrigated vegetation	Bare soil	Shrub/ xeric
Phoenix Greenwood	0.63	0.21	0.06	0.10
Central Phoenix	0.58	0.19	0.09	0.14
West Phoenix	0.63	0.13	0.10	0.14
Phoenix Super Site	0.59	0.21	0.08	0.12
South Scottsdale	0.61	0.17	0.07	0.14
Palo Verde	0.00	0.00	0.62	0.38

West Phoenix Air Monitoring Site

Central Phoenix Monitoring Site

Figure 1

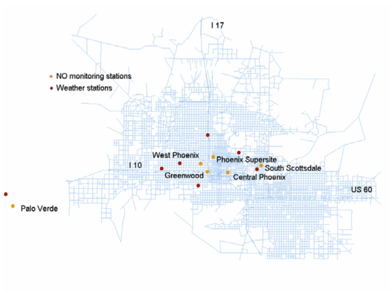
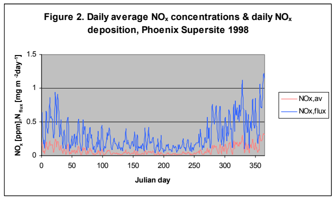


Table 2:

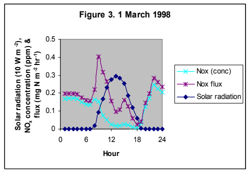
Annual deposition	NO	NO_2	NO_x [kg ha^{-1} year^{-1}]
Phoenix Greenwood	0.1	6.0	17.9
Central Phoenix	0.05	5.2	11.7
West Phoenix	0.06	4.3	10.6
Phoenix Super Site	0.05	4.6	11.0
South Scottsdale	0.03	3.7	7.4
Palo Verde	0.001	0.3	0.4

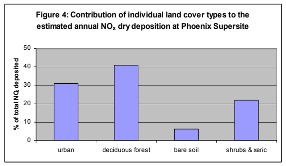
2. *Land use data*: The land use data were obtained from a digitized land use classification derived from LANDSAT TM at a resolution of 30m x 30m Stefanov *et al.* (2001), combined with detailed ground survey data on surface cover and vegetation types at 204 sites across the study area (Hope *et al.* in prep - survey 200 data). The land use categories were grouped into 6 major land cover types which are distinct for the process of atmospheric dry deposition (urban, agricultural land, barren soil, shrubs, water, deciduous trees). The proportion of each cover type in a 2 km x 2 km area around each monitoring station was extracted using GIS/ArcInfo (Table 1).
3. *Monitored data*: Hourly data on ambient concentrations of NO, NO_2 and NO_x were obtained from the air quality monitoring stations listed in Table 1. Five sites are located within the urban core area and one site in the surrounding desert. Meteorological data (hourly air temperature, dew point temperature, relative humidity, solar radiation, wind speed and direction at 10 m) were obtained from the NWS station at Phoenix Sky Harbor Airport as well as from PRISMS stations close to the air quality monitoring sites (Figure 1).



Results and Conclusions

1. *Annual fluxes*: The model was used to predict deposition fluxes of NO, NO_2 and NO_x for the entire year of 1998. The simulated annual NO_x dry deposition rates (Table 2) show that N deposition in the urban core area is significantly elevated above deposition at the non-urban Palo Verde site. Since the land use characteristics around the urban stations are similar we conclude that differences in the simulated deposition fluxes are caused mainly by differences in the measured pollutant concentrations. The Greenwood station is close to a major highway and therefore characterized by very high deposition rates, which are not representative for a larger area. The South Scottsdale station is outside the central urban core but well in the midst of an urbanized area.
2. *Seasonal variation*: Our model simulations show a marked seasonal pattern for the NO_x dry deposition fluxes, peaking over the winter months and declining during the summer (Figure 2). The seasonal trend is much less distinct for the predicted NO and NO_2 deposition fluxes (not shown).
3. *Diurnal variation*: We detected a repeatable diurnal pattern in NO_x concentrations which peaked during the early-mid morning period, dipping during the middle of the day and then increasing again during the late evening (except in the case of strong winds). NO_x deposition fluxes follow the variation in NO_x concentrations closely (Figure 3).
4. *Sensitivity analysis*: The most important determinants of N deposition fluxes are ***ambient concentrations of NO_x species*** in the atmosphere and the ***amount of vegetated surface cover***. Figure 4 shows the contribution of the individual land use types to the total annual NO_x deposition flux at the Phoenix Supersite station.
5. Our simulations are within the range of modeled estimates quoted for the Los Angeles basin (Russell *et al.* 1993). In the Los Angeles study NO_x represents about 20 % of the modeled dry N deposition flux. Assuming the same ratio for the Phoenix area, N deposition fluxes would range from about 20 kg ha^{-1} y^{-1} for the desert areas and 50 kg ha $^{-1}$ y^{-1} for the urban core areas. Those numbers agree well with estimates from Baker *et al.* (2001).
6. Future work will include short-term simulations with the air quality model Models-3/CMAQ to obtain detailed spatial predictions of N-deposition fluxes as well as estimates of fluxes of other pollutants. The Models-3 aggregation option will be used for the simulation of seasonal and annual average deposition fluxes based on weather classification.





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References

Baker LA, Hope D, Xu Y, Edmonds J, Lauver L. 2001. Nitrogen balance for the Central Arizona-Phoenix (CAP) ecosystem. Ecosystems **4**: 582-602.
Bolin B, Aspling G, Persson C. 1974. Residence time of atmospheric pollutants as dependent on source characteristics, atmospheric diffusion processes and sink mechanisms. Tellus **26**: 185-195.
Hanna SR, Chang JC. 1992. Boundary-layer parameterizations for applied dispersion modeling over urban areas. Boundary_Layer Meteorology **58**: 229-259.
Hope D, Gries C, Carroll S, Zhu W, Redman CL, Grimm NB, Nelson A, Kinzig A. In prep. The role of humans in structuring the ecosystem properties of cities. Science.
Jarvis PG. 1976. The interpretation of the variations in leaf water potential and stomatal conductance found in canopies in the field. Phil. Trans. R. Soc. London B **273**: 593-610.
Larcher W. 1994. Photosynthesis as a tool for indicating temperature stress events. In: Ecophysiology of photosynthesis. Schulze ED, Caldwell MM (eds.) Springer Verlag Berlin Heidelberg, Germany. p. 264.
Russell AG, McRae G J, Cass GR. 1993. Mathematical modeling of the formation and transport of ammonium nitrate aerosol. Atmospheric Environment **17**: 949-964.
Stefanov WL, Ramsey MS and Christensen PR. 2001. Monitoring urban land cover change: An expert system approach to land cover classification of semiarid to arid urban centers. Remote Sensing of Environment **77**: 173-185.
Walmsley JL, Wesely ML. 1996. Modification of coded parameterizations of surface resistances to gaseous dry deposition. Atmospheric Environment **30**: 1181-1188.