How nucleation modifies precipitation: an experiment

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Nucleation mode aerosols are after subsequent growth the main contribution in remote areas to the accumulation mode. Still to small to be visible and to interact with radiation they can have a significant impact on cloud microphysics as soon as they become cloud condensation nuclei, CCN. These additional CCN modify the cloud albedo and potentially suppress precipitation in warm clouds. Hence impacts on regional climate can be expected from any substantial modification of aerosol precursor emissions, which may be either due to change of land use or following climate change, though the quantification is as difficult that the indirect effects of aerosols still are the main uncertainties in climate modelling (CCSP, 2009). It's difficult to proof the model results due to the high spatial and temporal variability of all processes involved and special experimental boundary conditions are required to be able to indentify the impact of changes in the aerosol populations. Within a worldwide unique natural laboratory in Western Australia new sources of nucleation mode particles linked to human impact could be identified which can explain the observed redistribution of precipitation which was observed within the last four decades.

Western Australia suffers from a significant (about 25%) reduction in precipitation which started in the seventieth of the last century and continued with a tendency to even lower precipitation rates in the last decade (IOCI, 2002). This sudden drop in precipitation rates was attributed to a change in the circulation patterns of the southern Indian Ocean. Global climate models indicate that the south western tip of the continent, the Australian wheat belt has to expect even warmer temperatures and less rain in the future. An interesting feature is that the native vegetation in the east of the wheat belt seems to get slightly more rain than previously, although this is on a far lower level than the regions closer to the coast. Within several experiments in the nineties of the last century meteorological investigations were performed along the "Bunny Fence", a 1500 km fence that separates agriculture and natural vegetation using aircraft and ground based instrumentation to characterize meteorology on a local to regional scale. The results showed a distinct influence of the different albedo and vegetation on both sides of the fence on micrometeorology, water vapour fluxes and regional convective energy distribution (Lyons et al, 1993/ 1996). Though more water vapour is present above the region where thousands of square km were converted from scrubland to agriculture cloud bases are lower due to lower surface temperature than above the natural vegetation and apparent clouds generate less precipitation. Satellite images indicate a higher presence of clouds just along or east of the fence which acts not only a surface barrier against rabbits, emus and dingos but also as a meteorological line dividing two different regimes (Lyons, 2002). Within a new experiment we included aerosol measurements into an aircraft payload for the investigation, whether local advection, regional or large scale transport or other parameters like surface roughness or aerosols might be responsible for the well documented precipitation distribution. Recently model calculations with reduced surface roughness above arable land were used to explain the low precipitation over the agriculture (Pitman et al, 2004) which also would require a large scale transport of humidity passing over the agriculture without rainout by convective activity. Our aerosol measurements showed that a significant cross fence transport system was not detectable and nucleation mode aerosols had a significant impact von the cloud microphysics and subsequently on precipitation.

Experimental

The research area extends to both sides of the 'Bunny Fence' which is also called the 'State Barrier Fence' along an west-east road connecting Lake Grace / Newdegate in the wheat belt with Norseman in the outback. The area, an ancient absolutely flat cratoon, is covered with thousands of small and large salt lakes which are lined up in the river old beds. The western part, the wheat area was converted mainly between 1920 and 1980. Settlements and population are that low that no significant impact of anthropogenic activities can be observed. The next larger city is Perth, about 400 km away. Fig. 1 shows the area in Australia, summer and winter agricultural conditions and the marked change in surface patterns along the fence. We flew a small aircraft, based on a motorized glider which was equipped with a scanning mobility particle sizer (GRIMM SMPS), an optical particle counter (GRMM Model 1.108) and a condensation particle counter (TSI3010), micrometeorological instrumentation and radiation instruments. For cloud characterisation a forward scattering spectrometer probe (FSSP-100) was added. Standard flight patterns were racetracks about 150 m above ground along the road reaching into each regime by up to 100 km. At the turning points of the racetracks vertical profiles up to 4000 m were added to probe the planetary boundary layer and its vertical homogeneity.

Fig. 1: Location of the experiment in Western Australia, salt lakes in the agricultural area and sharp change of surface patterns at the 'Bunny Fence'

On one day, August 21, 2007 we found 4-5 octa cumulus clouds over both sides which allowed to probe both, the aerosol vertical distribution and the corresponding cloud droplet size distribution over both areas.

Results and discussion:
In other areas of the world nucleation mode particles in remote areas were found typically over forested areas (Kulmala et al, 2004) and the production of particles was explained as a reaction of biogenic emissions, sulphur dioxide and water vapour under the influence of ultraviolet light the conditions in Western Australia were completely different. Although the trees in the native vegetation are isoprene emitting eucalyptus species and the agricultural vegetation is not emitting any aerosol precursors we found nucleation mode particles exclusively over the arable land. In the east particle numbers were low, close to continental background levels (Biggs and Turvey, 1984) of about 600 to 800 ultrafine particles per cm3, and none below 15 nm diameter. In the west over the wheat ultrafine particles counted up to 20000 per cm3 and consisted from a large fraction of nanometer size aerosols. Size and number distributions behave exactly like the typical 'banana' curve aerosol from other nucleation mode studies. In the morning at about 11 am most particles were below 6 nm with a minimum in the distribution at 15 nm while in the afternoon at 2 pm most particles were larger than 25 nm and the maximum at low nm sizes vanished. Growth rates were in the order of 6 nm/h. As the source for aerosol precursor emissions we identified selected smaller salt lakes. There was no indication of any biogenic emissions from the vegetation and enhanced particle numbers were always located over salt lakes. Not all the lakes were active and lakes in the native vegetation zone were never seen to produce particle precursors. This pattern was independent on the season and the vegetation cover in two seasons, winter and summer and as nanometer particles were found only over the arable land it excludes a strong local advection flow over the fence into the national park. Also the strong differences in the convection with planetary boundary layer thickness 500 m larger over the nature did not lead to and seabreeze like exchange flow. The differences in the salt lakes on both sides are due to the different ground water levels. The ground water table in the cultivated land rose from 20 m in 1970 to about 2 m in 2000 accompanied by a significant salinification of drinking water. This behaviour of the groundwater table could be attributed to deforestation. The lakes in the west are occasionally coupled to the ground water table. Different humidity levels drive biogeochemical reactions which in turn lead to emission of aerosol precursors, most probably organo-halogenides. As we had no instrumentation for chemical specification of aerosols on board we were not able to investigate the particle chemistry.
The particles produced by the salt lake emissions grow like other nucleation mode aerosols in size and reach cloud condensation nuclei sizes after about 5-6 hours. Hence while the total number of ultrafine particles/ cm3 above 10 nm in the west was ten fold the number in the east the number of cloud condensation nuclei (> 50 nm) was doubled over the agricultural land. How does this affect precipitation?
On one day we had the chance to compare aerosol distributions below cloud and cloud droplet size distributions over both regimes within about 2.5 hours flying time.

The results are given in the table.

Table: Meteorological and cloud physics parameters below and within cloud

Parameter	West (agriculture)		East (natural vegetation)	
	ground	cloud base	ground	cloud base
Temperature [°C]	16	10	20	6
Pressure [hPa]	975	900	975	800
Dewpoint [°C]	11	9	6	3.5
Water [g/m3]	9.9	8.8	6.9	6.1
Cloud droplets [/cm3]	247		198	
Average diameter [um]	8.3		9.5	
Liquid water content [g/m3]	0.10		0.15	
Droplets > 15 um [/cm3]	1.5		3.4	

Although we found more water vapour below cloud base in the west this water vapour was not reflected in the clouds. Average droplet diameter and liquid water content were lower and the number of droplets was higher than in the east. Also the number of cloud droplets larger than 15 um were significantly higher in the east. Droplets of this size are required to initiate raindrop production in the cloud. Though the cloud in nthe east was at a higher pressure level the vertical extension of the clouds on both sides was similar and both cloud fields consisted exclusively of warm clouds.

Literature:

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