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Architecture and Processes for National Ion Coverage Maps

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Abstract: Salt accumulates on the land's surface via rainfall washout of dissolved ions and via dry deposition of salts attached to suspended dust particles. Local and regional studies, based on point data have provided an understanding of accession processes, but have not been compiled as a coherent spatial coverage for Australia, nor assessed in a temporal context, as is routinely carried out for northern America. This paper describes an information system which couples spatial analysis of salt accession modelling with GIS, to deliver national accession maps over the World Wide Web (WWW).

We illustrate this system through examination of chloride accession data across Australia. As ion accession is a spatially contiguous process, it is important to place the site-specific information into a surface Expanding from a point-based representation to a surface provides a richer means of visualisation, and hence analysis, of the geographic variation of chloride.

The key components of this system (Figure 1) are: a relational database to store site observations for modelling; the modelling application; a geospatial database to store spatial layers; and a web map application for visualisation.

We use an empirical model to estimate the deposition of chloride (kg/ha) across Australia. This follows previous research which related chloride accession to rainfall, wind direction and distance from the coast. The model was developed using The Invisible Modelling Environment (TIME) in the C#.NET programming language. It also exploits the Surfer application to assist with interpolation of site observations from the relational database.

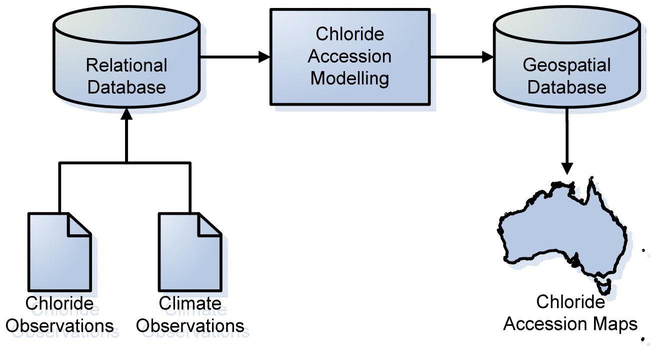

Figure 1. Chloride accession information system.

To account for the natural variability of the atmosphere, Australia was subdivided into Uniform Geographical Units (UGUs) characterised by Australia's climatic zones. Grid cells within each UGU were parameterised based on chloride concentrations measured in rainfall at sites within each UGU. A base chloride accession map was generated from the aggregate of ~200 chloride observations across Australia. The approach was tested by comparing observed values to the modelled base accession map. Correlation gave an r^2 of 0.72.

Chloride accession grids were stored within an ESRI geospatial database. The OpenGIS Web Map Service (WMS) standard was used to request the geo-referenced maps from the database, allowing them to be delivered over the internet to WMS compatible clients. An interactive web map application was developed using ArcGIS Server to view the maps via a WWW browser.

Ongoing work focuses on extending the system to produce temporal chloride accession coverage maps. This spatio-temporal data will provide a mechanism to produce coverage animations, based on the on-going collection of point-based accession data. Emphasis will be placed on the automatic generation of these maps on a regular basis.

Keywords: *Relational database, Salt accession, GIS web delivery, Regression analysis, Maps*

1. INTRODUCTION

Knowledge of salt accession to the landscape aids the spatial and temporal understanding of salinity processes and groundwater recharge and provides information that can help unravel groundwater movement through aquifers. Chemistry of rainfall at a number of sites across Australia has been collected by a number of researchers (e.g. Hutton, 1976; Hingston & Gailitis, 1976; Keywood, 1995), and continues through a network of rainfall collectors across the continent. We require a desktop delivery system which will allow this data to be delivered electronically over the internet, and easily and quickly updated as further information is acquired.

The objective of the system described here is to deliver time series coverage maps of various ions such as chloride, sodium, calcium, magnesium, potassium, sulphate and nitrate via the web. The coverage maps are generated from rainfall chemistry data collected from field sites across Australia. Due to the limited number of field locations, relationships between the ion data and climate data must be modelled and used to interpolate accession rates where data are sparse.

Previous work (e.g. Hutton, 1976; Keywood, et al., 1997) has shown that distance from the coast, wind, and rainfall are all factors which contribute to the amount of salt accession, hence all need to be considered in the models. The approach we use here uses the distance from the coast via the prevailing wind trajectory, only considering wind direction data if rainfall was also recorded for the same period. This distance value is then used as an input to our chloride accession model.

Comparisons of chloride accession relationships and their spatial distribution suggest accession rates vary due to climatic variability across Australia. Hence, Australia is divided into Uniform Geographic Units (UGUs) representing Australia's climatic zones, whereby each UGU is modelled individually and re-assembled to form a complete coverage map.

Whilst the system described here is applied to generation of a base chloride accession map for Australia, the principles apply to accession of any atmospherically-derived ion. The base map is generated using historic chloride concentration observations from numerous sources, and uses aggregated climate data retrieved from the Bureau of Meteorology (BOM) to develop the wind patterns.

2. METHODOLOGY

The system used for the generation of ion coverage maps is illustrated in Figure 2. The system is based on a 3-tier architectural model consisting of 2 stages (or steps); the temporal point data, and the temporal grid data. The database layer handles persistency of the data, the business logic layer captures the core of the system, and the application layer defines how the user interacts with the system. The structure of this section will be based upon this model.

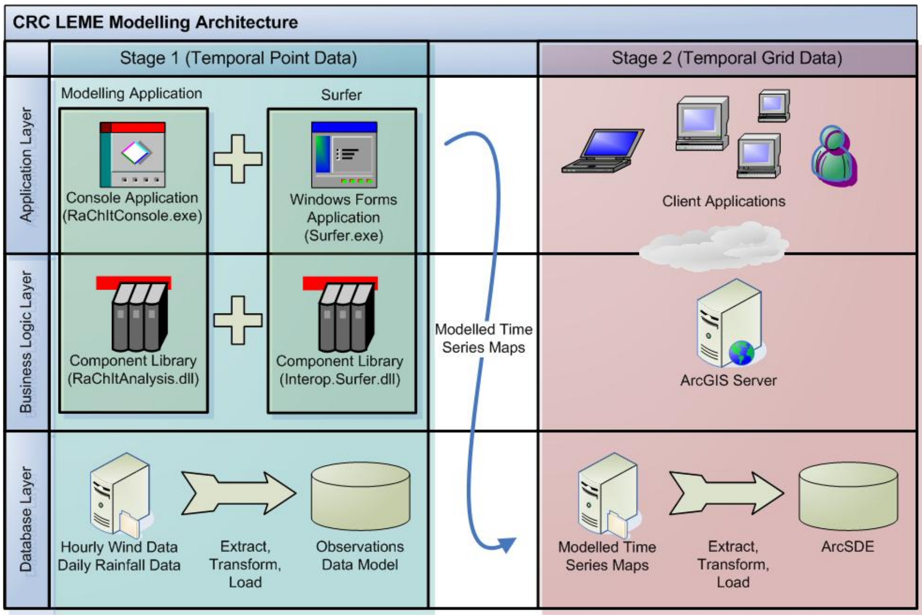

Figure 2. Model of system architecture used to produce national ion coverage maps.

2.1. Stage 1 (Temporal Point Data)

2.1.1 Database Layer

Hourly wind direction and daily rainfall data are sourced from 1682 monitoring stations maintained by the BOM, and supplied via an annual subscription to their FTP site. These stations are shown in Figure 3. The data are imported into a SQL Server relational database which uses the Observations Data Model (ODM) Schema (Horsburgh, et al., 2008). Several SQL Server Integration Service (SSIS) packages retrieve the data, and perform the data integration which is scheduled to run on a monthly basis.

From the wind direction and rainfall data, the most frequent (mode) wind direction at each site is derived when it is raining. Because of different temporal resolutions between the wind and rainfall datasets, all wind direction values for the 24 hours prior to the rainfall data record are used to calculate the mode, except when the wind is calm. Wind direction is a continuous data type, so wind direction data are reclassified to 16 cardinal directions before calculating the mode. This process is executed via SQL Server Stored Procedures at the database layer and has been configured to derive the following modal datasets:

Figure 3. Bureau of Meteorology Monitoring Stations used to provide climate data for the accession modelling process.

- Monthly modal wind direction at each station (continually updating)
- Seasonal modal wind direction at each station (continually updating)
- Annual modal wind direction at each station (continually updating)
- Modal wind direction of all historic data at each station (Run once, Ending: 30/4/2007)
- Modal wind direction of all historic data for each of the four seasons at each station (Run once, Ending: 30/4/2007)

The relational database also serves to store the chemistry data derived from the rainfall samples. This data can be imported from a spreadsheet using the ODM Streaming Data Loader, and analysed using ODM Tools.

2.1.2 Business Logic Layer & Application Layer

Modal wind direction values for each site are retrieved from the database and interpolated across the whole of Australia to obtain prevailing wind direction grids at the temporal resolution of interest. These grids are calculated using a combination of TIME (Rahman, et al., 2003) and the Surfer® application developed by Golden Software®.

Wind vectors are converted into their respective X and Y components, interpolated using the kriging algorithm, and then reassembled back to a directional grid using appropriate trigonometry. This process is achieved by invoking functions within Surfers® Application Programming Interface (API). From the directional grid the mean distance to the coast is calculated to each cell using a modified version of Dijkstra's shortest distance algorithm (Dijkstra E.W., 1959) which is used as the *x* variable in the chloride relationship (*see below*: section 3.1).

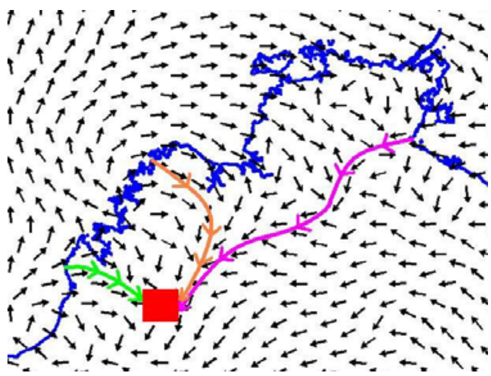

Figure 4. Demonstration of 3 possible wind trajectories which could have been used in determining the mean distance to a hypothetical grid cell in north-western Australia.

The coverage maps are geographically divided into UGUs based on varying climates (*see below:* section 2.2), and individual relationships are applied directly to each UGU. Data values are then sampled at control points and interpolated once again at a higher resolution (5 km) to produce the final coverage map. Using a Calculate first, Interpolate last (CI) approach, permits field observation data to be incorporated with the sampled control points, as the data becomes available on a regular basis. The locations of the control points varies, with more dense control points being taken near coastal areas, and less dense control point being taken inland, and near the boundaries of each UGU. This allows the higher varying accession rates near the coast to be captured, while also concealing the different relationships between neighbouring UGUs. Figure 4 shows the density of the control points used to generate the coverage grids.

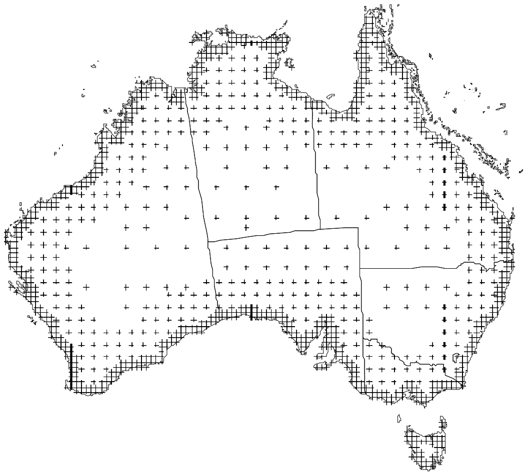

Figure 5. Control point density used for interpolation of chloride accession maps.

The interface to execute model runs is in the form of a windows console application which accepts parameters as arguments. This allows for easy execution of model runs from a scheduler to assist with automating the process of generating coverage maps.

Chloride accession grids, and other data derived in the modelling process are saved to a file server.

A user interface has been developed to allow the user to visualise and retrieve datasets (climate and chloride) within the relational database. The time series data values can be viewed in Google Earth (Figure 6) using the ODM2KMZ Gateway[1], and entering the LEME WaterOneFlow Interface URL[2] where required.

2.2. Stage 2 (Temporal Grid Data)

2.2.1 Database Layer

An ESRI ArcSDE geodatabase has been created on the database server. This geodatabase is used to store the time series coverage grids which are generated through stage 1. Coverage grids are currently inserted into the database manually; tools to perform spatial data importing into Geodatabases and compression will be investigated in future studies.

2.2.2 Business Logic Layer & Application Layer

Coverage grids are added as layers to a map using ArcMap and deployed as a Map Service using ArcGIS Server. At present there is no known way to automate this task. Templates can be created and this can serve as a quality control mechanism whereby the maps are required to be reviewed before being made available to the public.

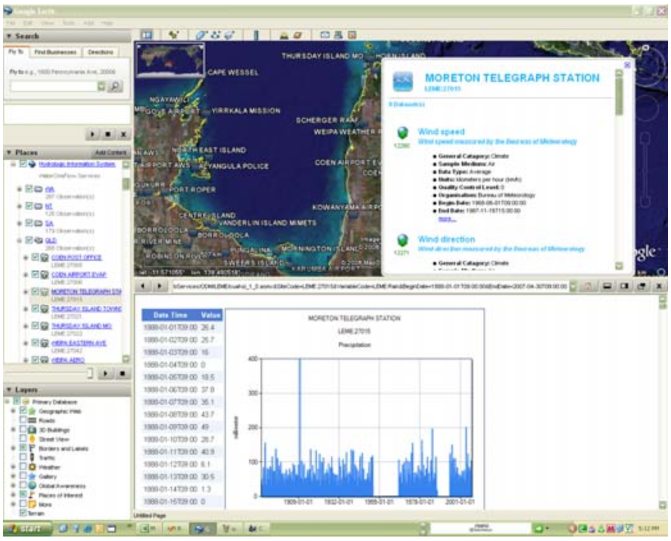

Figure 6. Google Earth displaying datasets for a site. Upon selection of a site, datasets for various parameters at that site are presented in a bubble. The user may then click on a dataset to view the values in both tabular and chart formats.

[1] ODM2KMZ Gateway URL: http://www.wron.net.au/webapps/histokml/odm2kmzgateway.aspx

[2] WaterOneFlow URL: http://www.wron.net.au/webservices/odm/leme/cuahsi_1_0.asmx

An interactive web mapping application has been developed which can be used to view the coverage maps via web browser[3]. The application currently supports zooming, panning, controlling visible layers and the ability to identify raw data values from the maps. Figure 7 shows a screenshot of the web mapping application displaying the base chloride accession map.

An OpenGIS® Web Map Service (WMS) has also been enabled for the chloride layers to be served from the Geodatabase and rendered in a pictorial format such as PNG, GIF or JPEG. This allows the coverage maps to be visualised in any WMS client such as Google Earth, gvSIG, NASA World Wind, OpenLayers, uDig and Qgis.

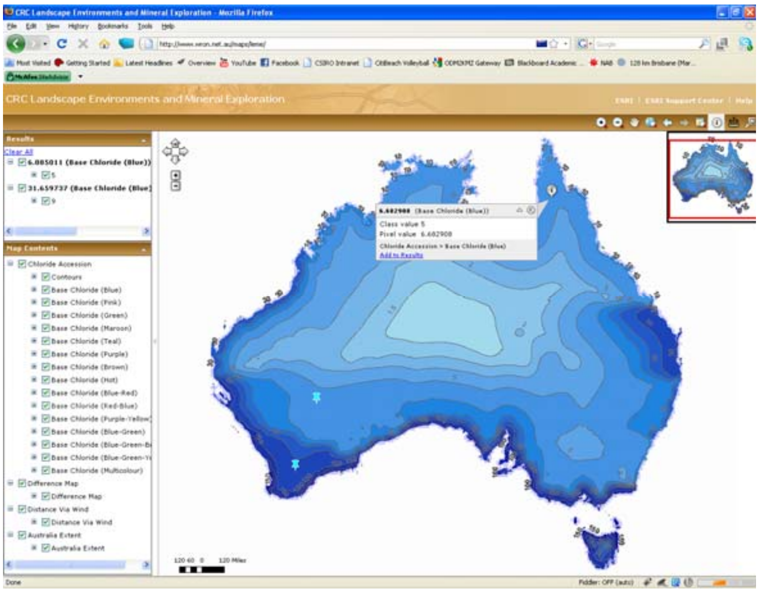

Figure 7. Base chloride accession coverage map (kg/ha) displayed in web browser illustrating identification of values.

3. MODELLING CHLORIDE ACCESSION

Australia has a defined climatic zonation. The analysis of chloride accession, therefore, is undertaken across distinct Uniform Geographic Units (UGUs) which are subsequently integrated to generate a map for Australia. As most of the salt deposited on land falls in rainfall, the UGUs are based upon the major seasonal rainfall zones of Australia (Figure 8).

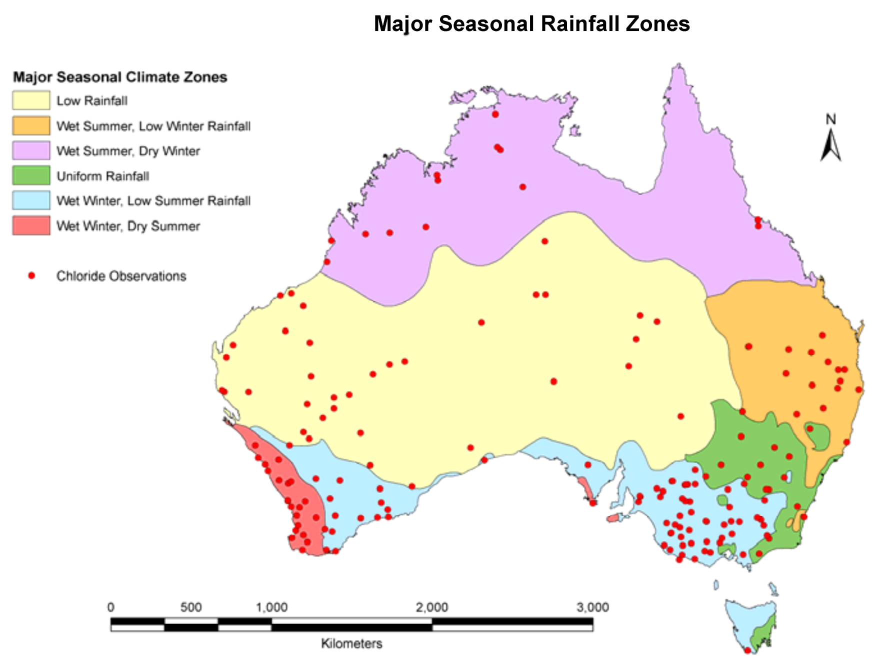

Figure 8. Major seasonal rainfall zones of Australia. Locations of chloride observations used to perform the regression analysis for the base accession map are also indicated.

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[3] Web Map Application URL: http://www.wron.net.au/maps/leme/

3.1. Regression Analysis

Keywood, et al. (1997) demonstrated that chloride accession decreased with increasing distance from the coast and could be described by the sum of two exponentials. Cresswell (2005) showed that a general form of this equation applied across Australia is as follows:

$$y = A_1 e^{\left(-x/\lambda_1\right)} + A_2 e^{\left(-x/\lambda_2\right)}$$

where: x is the distance from the coast, and A_1 and λ_1 are empirical parameters that describe a short-distance relationship, while A_2 and λ_2 describe a far-distance relationship, that vary around the country. Different parameter values typify the different climatic zones (Figure 9; Table 1). This type of relationship has been used for all UGUs to produce the base chloride accession coverage map for Australia.

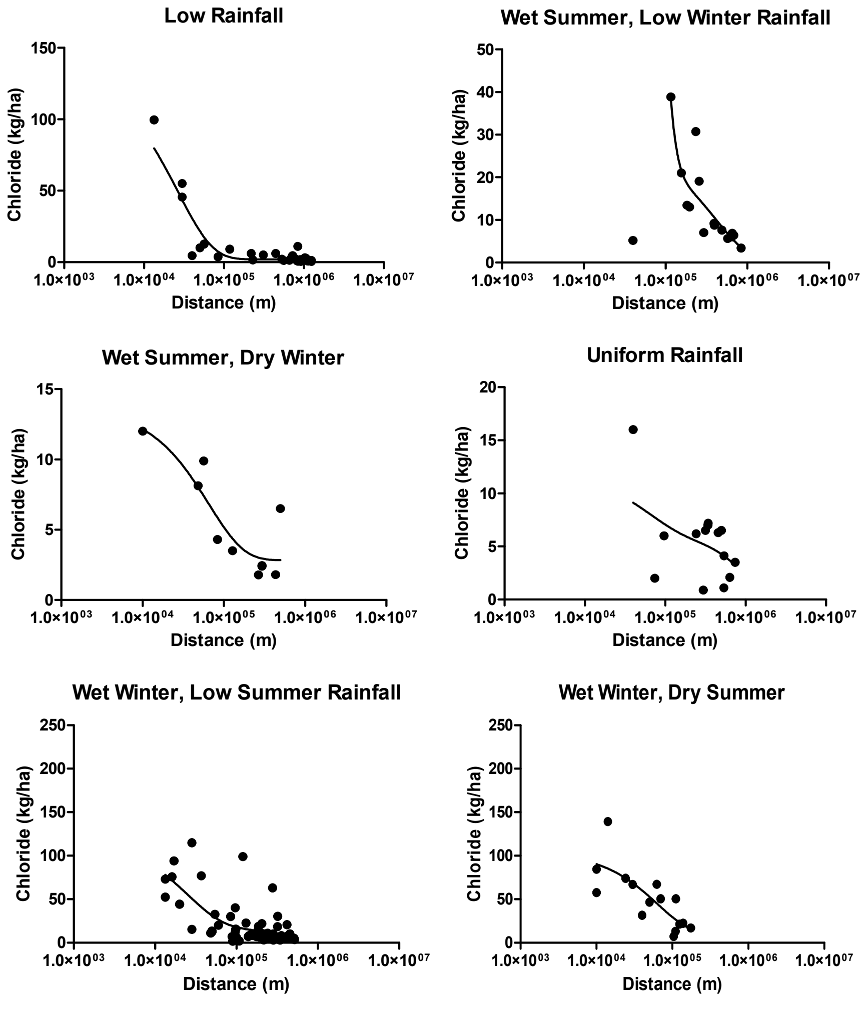

Figure 9. Chloride accession rates plotted against distance from coast (in the direction of prevalent wind direction) for the 6 climate zones shown in Figure 8.

Climate Zone	Parameters				r^2
	A_1	λ_1	A_2	λ_2	
Low Rainfall	1.01E-09	14,968	130.0	26,795	0.87
Wet Summer, Low Winter Rainfall	4578	20,881	28.1	408,163	0.76
Wet Summer, Dry Winter	10.9	65,445	2.8	4.77E+15	0.85
Uniform Rainfall	5.5	58,685	6.6	1,162,385	0.37
Wet Winter, Low Summer Rainfall	100.4	24,752	19.9	477,099	0.61
Wet Winter, Dry Summer	93.9	63,492	10.1	2.26E+14	0.60

Table 1. Parameterisation of individual UGUs

Our approach was validated by extracting modelled values from the base map at the locations of the chloride observations and comparing to the observed data. Modelled chloride accession provides a reasonable approximation of the observed values (Figure 10), with an overall r^2 of 0.72. This result provides confidence our approach will work adequately for generating coverage maps where observed data is sparse.

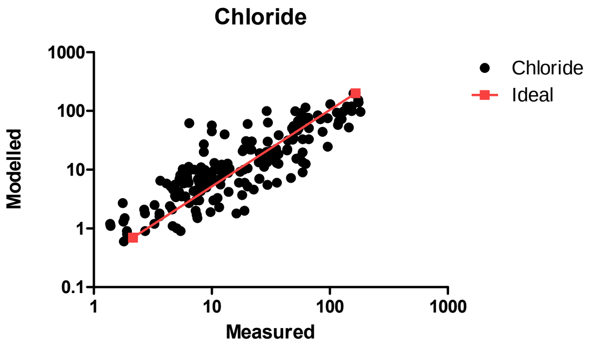

Figure 10. Modelled versus measured values of chloride accession across Australia.

4. DISCUSSION AND CONCLUSIONS

An accession modelling system has been built to electronically deliver time series maps for various ions measured in rainfall chemistry. The system was used to generate a base chloride accession map which used the aggregate of all historic climate observations (wind and rainfall) from the BOM as inputs to the chloride modelling process. The results demonstrate the rapid decrease in accession away from the coast, and influence of climatic zones (Keywood, et al., 1997) on the concentration of salts deposited on the land's surface.

Complete automation of the accession modelling system has not been achieved, but is possible with further development. It is preferable, however, to maintain a level of manual intervention to permit quality checks on the data and outputs.

Rainfall chemistry sampling varies from single events to combined quarterly samples; hence the chloride-distance relationship is driven by modal wind patterns that may not be indicative of the prevalent wind direction during the period of maximum accession. Records indicate the major rainfall events and more detailed analyses could be carried out with further resources and time. To support this, collection of rainfall chemistry data from twenty sites across the country continues.

The study has demonstrated that near real time analysis and display of the chloride accession to Australia can be achieved. Interpolating both; measured observations; and modelled discrete data where observations are sparse, will provide a realistic impression of the spatial variability in chloride accession.

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