Spatiotemporal analysis of airflow over hills

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1 Introduction

Over the past 15 years, there has been a gradual shift away from a purely deterministic approach to weather forecasting towards a more integrated probabilistic approach. In particular, methods such as meteorological data assimilation, ensemble forecasting and post-processing of numerical weather prediction model output have been influenced by theories from statistics and control theory.

Like any mathematical modelling of a complex dynamic system, the traditional deterministic approach to weather forecasting seeks to solve nonlinear partial differential equations. This is not possible by precise analytical methods, but is achieved by numerical approximation, integrating forward in time simplified versions of these differential equations. Limitations in this arise due to the deterministic chaotic nature which such geophysical processes exhibit (i.e. a system that is ordered and predictable but in a highly mathematically complex fashion), together with limitations in computing power for such high order systems.

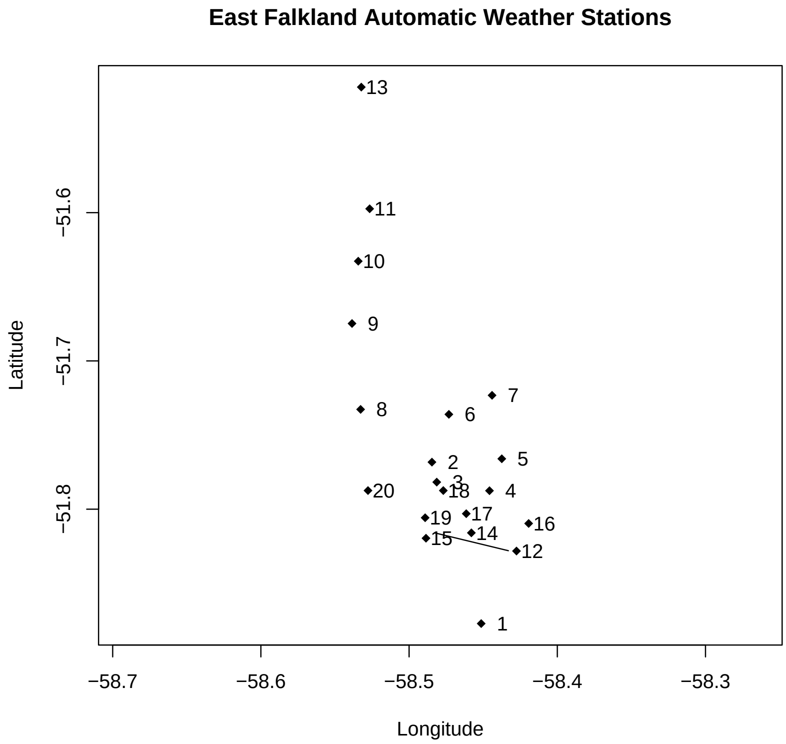
Data assimilation improves on numerical weather forecasting accuracy through the combination of deterministic modelling and observational data. In short, data assimilation inserts spatially weighted observational data into a deterministic model to constrain the model to more accurately represent the "true" atmospheric state. Usually data assimilation proceeds sequentially with time, while the model organises and propagates forward information from previous observations. The information from new observations is then used to modify the model state, to be as consistent as possible with the observations and the previous information. Lorenc (1988, 1995) discusses the Bayesian theory behind this methodology.

2 Motivation

Data assimilation may be considered an umbrella term for a variety of different techniques applied to achieve the objectives outlined above. A variety of such techniques are currently being utilised in most operational global and regional weather forecasting models worldwide with demonstrable success; however, until now no widely recognised data assimilation scheme has been developed for use in local weather forecasting models (of the order of 10's of kilometres).

At such high resolution, a numerical weather prediction model must ideally take into account a number of other factors, namely the effect that topography, that is the surface features of a region, has on atmospheric conditions. A number of atmospheric phenomena are known to occur as a result of atmospheric flows passing over hilly or mountainous terrain. In particular, atmospheric flows combined with certain regimes of temperature profile within the atmosphere can lead to quite disruptive turbulent events which are extremely difficult to predict via purely deterministic means.

Vosper (2003), from the UK Met Office, has developed a 3-dimensional numerical weather prediction model for application at such high resolution, it is the aim of my research to develop a data assimilation scheme for this model in order to more successfully predict the occurrence of such weather phenomena.



3 Experimental Data

During 2000 and 2001, an array of 20 automatic weather stations was used to collect high temporal resolution surface data in order to characterise the occurrence of weather phenomena in the Falkland Islands. An example of severe turbulence occurs in the lee of two mountain ridges, each of approximately 600m in height, on East Falkland. This phenomena is routinely observed from the island airport situated at Mount Pleasant and presents a severe aviation hazard.

The diagram overleaf shows the final sites chosen for the weather stations, with a large number clustered around the airport to capture surface data in this region. Prior to the field experiment it was not known what the optimum positions of sites would be in order to maximise the amount of information captured. The positions of the stations are not topographically equivalent with some being placed on the top of ridges and others being situated at the bottom of valleys between ridges. Several stations are situated in extremely close proximity to the runway itself (shown).

The 20 automatic weather stations recorded data as 30 second averages over a period of approximately one year, meaning a potential maximum of around 1,051,200 records per station over the duration of the experiment. However, due to the nature of the experiment, some of these stations performed better than others and data sets between stations range from sporadic to near uninterrupted.

The high resolution data assimilation methodology being considered envisages that via statistical interpretation of the spatial and temporal data, appropriate weightings may be attributed to observations collected at certain weather stations. In turn these weighted observations will hopefully lead to the development of statistically derived ”nudging constraints” to be incorporated into the three-dimensional weather prediction model developed by Vosper (2003), to improve its forecast accuracy.

4 Exploratory Analysis

Given such a large experimental data set a lot of time-consuming pre-processing of data is required to remove erroneous values, and present the data in a workable form.

As a first step in the assimilation problem, it is essential to understand the general underlying temporal and spatial behaviour and distribution of the data. Some exploratory statistical analysis performed on the data set brings out interesting features.

Prior to any weightings being attributed to the observational data, the relative significance of each station needs to be ascertained. Principal component analysis was performed on the dataset with the aim of reducing its dimensionality whilst preserving most of the variability within it. The results are encouraging.

There are particular issues related to the high resolution data assimilation process problem given a spatially sparse data set, where interpolation and smoothing considerations are key. From the work of Mardia *et al* (1998), Sahu & Mardia (2004) and Bengtsson *et al* (2003), the application of Kriging and Kalman filtering techniques are under investigation. The Kriged-Kalman filter approach of Mardia *et al* (1998), and Sahu & Mardia (2004) as well as the non-linear ensemble approach of Bengtsson *et al* (2003) have great potential for this problem.

References

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