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A Pilot Study for the Collaborative Development of New Ways of Visualising Seasonal Climate Forecasts

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1. Introduction

Seasonal climate forecasts are used by climate scientists, government departments, utility agencies, health agencies and in agriculture. Uncertainties in environmental data and in numerical prediction models make such forecasts inherently probabilistic. Good decisions require that this uncertainty in predictions be communicated to users. Some established methods have limitations, prompting this collaborative work between data visualizers and climate scientists facilitated by the Willis Research Network[1].

We report on the methods developed and prototyped and summarise the informal feedback generated. This informal process is insufficient for forming wider conclusions, but we reflect upon this exploratory work to help inform a planned formal study of collaboration between visualisation and domain-specific experts to develop new and effective modes of visual exploratory data analysis in the domain.

2. Data

Precipitation forecast and observation data expressed as *precipitation anomalies* (deviation from the 25-year mean) for Dec-Jan-Feb periods over 25 years (1981-2005) were provided by ECMWF[2] via the EUROBRISA[3] project. Forecasts from ensemble models (multiple model runs with slightly differing initial conditions), were provided as *(a)* mean forecast anomalies and *(b)* probabilistic forecasts expressed in terms of lower (p_1), middle (p_2) and upper (p_3) terciles (33^{rd} and 66^{th} percentiles) corresponding to *below normal*, *normal* and *above normal* precipitation, respectively.

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[1] http://www.willisresearchnetwork.com/

[2] European Centre for Medium-Range Weather Forecasts (http://www.ecmwf.int/)

[3] http://www6.cptec.inpe.br/eurobrisa/

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3. Graphical techniques in use and their limitations

Graphical representations of seasonal forecasts are widely used by scientists and agencies. However, the inherent uncertainty that results from modelling dynamic natural systems and therefore the confidence one can place in these forecasts is not always shown effectively by existing approaches (see examples on Met Office, ECMWF, IRI and EUROBRISA websites[4]).

The tercile-based data summarise variation between ensemble members by allocating them into 'drier than normal', 'normal' and 'wetter than normal' tercile bins. These are expressed as probabilities; e.g. if 10% of the ensemble members predict 'drier than normal' conditions, 20% lie predict 'normal' and 70% predict 'wetter then normal', then p_{wetter}=0.1, p_{normal}=0.2, and p_{drier}=0.7. We express these as the lower (p_1), middle (p_2) and upper (p_3) terciles respectively.

Most current approaches either show the probability for only one tercile or they further bin p_1, p_2 and p_3 into nominal categories that may be rather arbitrarily defined, may not cover all scenarios and often use inconsistent colour schemes.

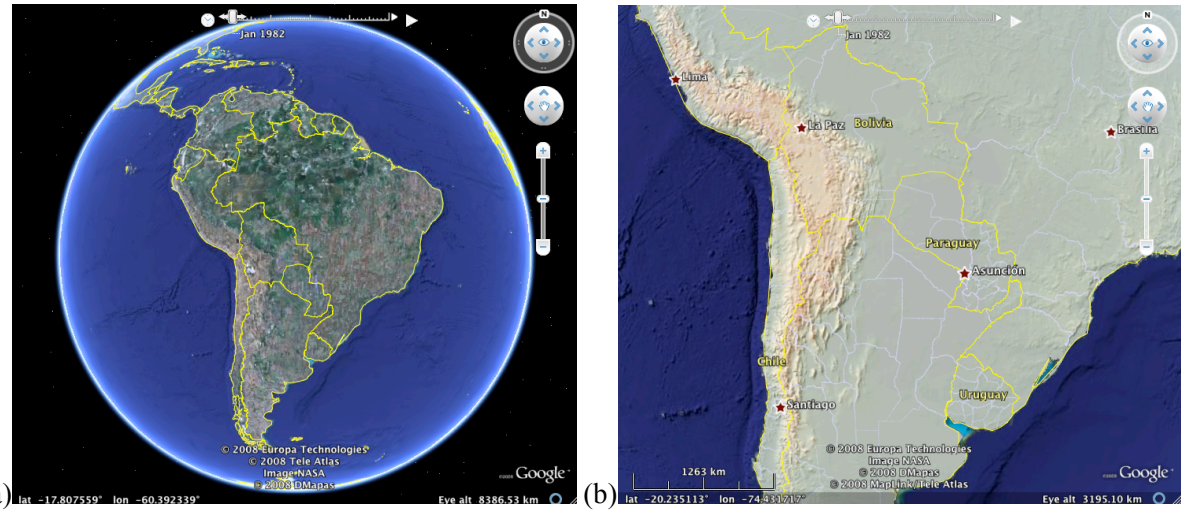


Figure 1. Background datasets in Google Earth.

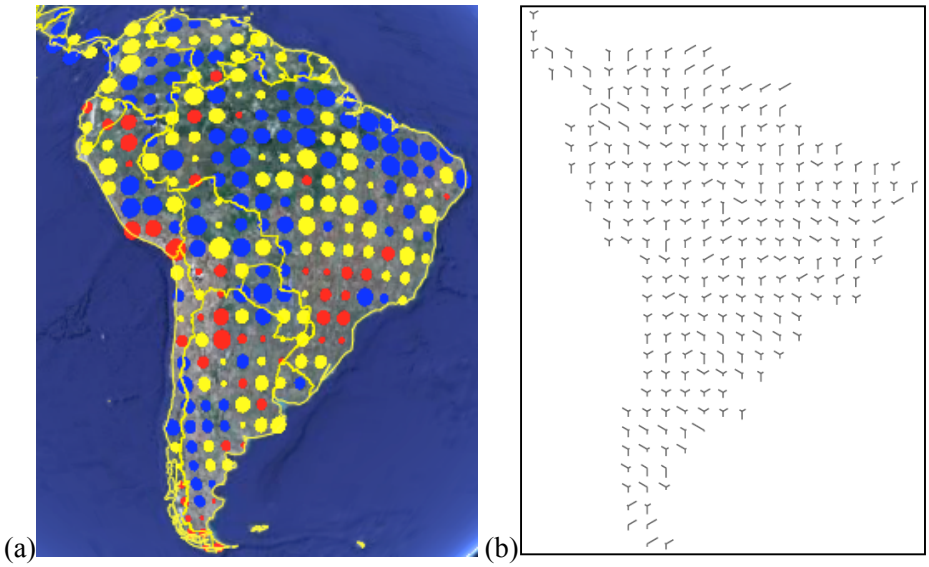
4. Prototyping ideas and feedback

We addressed some of these limitations through novel, interactive and animated 'data prototypes' that support the rapid development of visual ideas. Technologies[5] that enable 'patchwork prototyping' (Floyd *et al*, 2007) were employed including: SVG (Figures 2b and 4), KML (Google Earth), Processing (Figure 5) and R (Figure 2c). Google Earth provides built-in aerial imagery and background datasets (Figure 1), which many end-users liked and it was relatively easy to incorporate other datasets such as the elevation model in Figure 1b. The other technologies used are more general-purpose and offer more control over appearance and interaction. Researchers at Exeter University and EUROBRISA project members in Brazil provided informal feedback and suggestions. These users ranged from scientists to decision-makers based in Brazil. For this preliminary study, we did not gather specific requirements from our diverse set of users. Instead, we developed and prototyped ideas for addressing some of the limitations of existing technique identified by the climate scientists and invited informal feedback. This helped us to assess the feasibility carrying out our

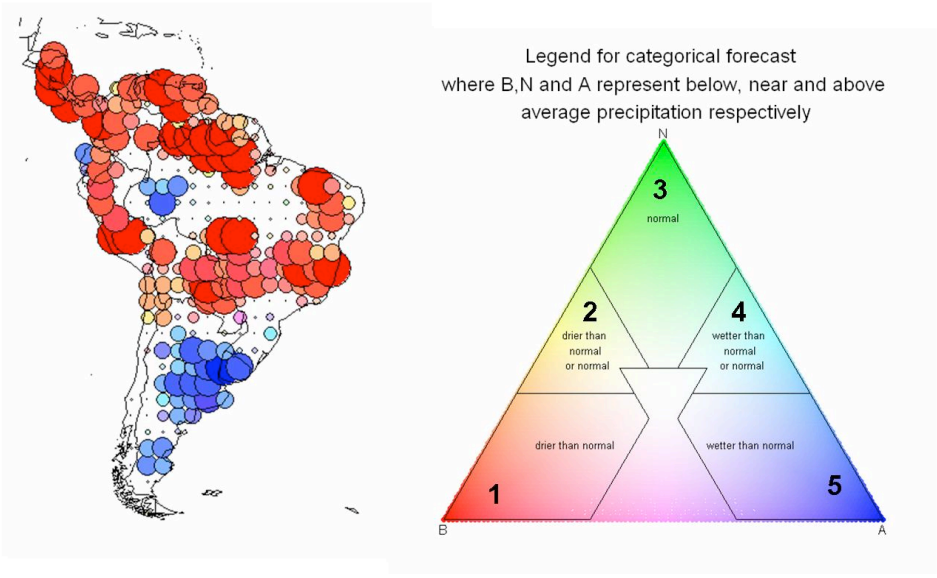
[4] http://www.metoffice.gov.uk/, http://www.ecmwf.int/, http://portal.iri. columbia.edu/ and http://www6.cptec.inpe.br/eurobrisa/

[5] http://www.w3.org/Graphics/SVG/, http://code.google.com/apis/kml/documentation/, http://processing.org/ and http://www.r-project.org/

formal study that will deal with specific user requirements from specific user groups of climate scientists at the UK MET office.



(a) (b)



(c)

Figure 2. Tercile-based probabilistic precipitation forecasts. *(a)* Circles coloured by dominant tercile and sized by the sum of the deviations between tercile probabilities; *(b)* Glyphs where arm lengths correspond to p_1, p_2 and p_3 (left, bottom and right arms, respectively). *(c)* The probabilistic forecast (left) is coloured according to the combination of the 3 tercile probabilities given within the colour space shown in the ternary phase diagram (right). Hue varies by angle from the centre and saturation varies by distance from the centre. Colour shows whether drier (p1; red), normal (p2; green) or wetter than normal (p3; blue) conditions are most likely. Corners denote a probability of 1 for each tercile (high saturation, high probability of rainfall in dominant tercile category) and the centre denotes equal probability for all terciles (low saturation, forecast no better than issuing climatology). *Colour is a necessary characteristic of this figure – obtain a colour PDF of this abstract from http://www.gicentre.org/papers/gisruk09/climate.pdf*

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4.1. Tercile-based probabilistic forecasts

To explore the design space with users we quickly generated initial ideas and prototypes that map different aspects of the data sets using various techniques. In Figure 2 information about all three tercile probabilities is visually encoded at each location concurrently for a single time period. In Figure 2a circles are sized according to the sum of the deviations between the *p*-values; thus the smallest circles occur where $p_1=p_2=p_3=0.33$, where the ensemble forecast tells us little beyond the known climatology. The largest circles occur where $p_1=1$, $p_2=1$ or $p_3=1$, with hue encoding the dominant tercile. User groups in Brazil found these maps easy to interpret. In Figure 2b, glyphs are used where the p_1 (left arm), p_2 (vertical) and p_3 (right) values are encoded through length, with Y-shaped glyphs denoting equal (1/3) probability for all terciles. In Figure 2c colour is derived from plotting the forecast on a ternary phase diagram. Circles are largest for forecasts at the corners and smallest in the centre of the diagram. Initial reactions of users to the latter two design ideas were less positive as they were less immediately interpretable. Sensible concerns were also raised about interpretation of colour by users with colour-impaired vision.

4.2. Comparison of observed and mean forecast precipitation anomalies

Figure 3 compares observed with mean forecast precipitation anomalies. Although there is general agreement between whether observed and modelled precipitation anomalies are positive or negative, observed anomalies were more extreme in magnitude and exhibit stronger spatial patterns.

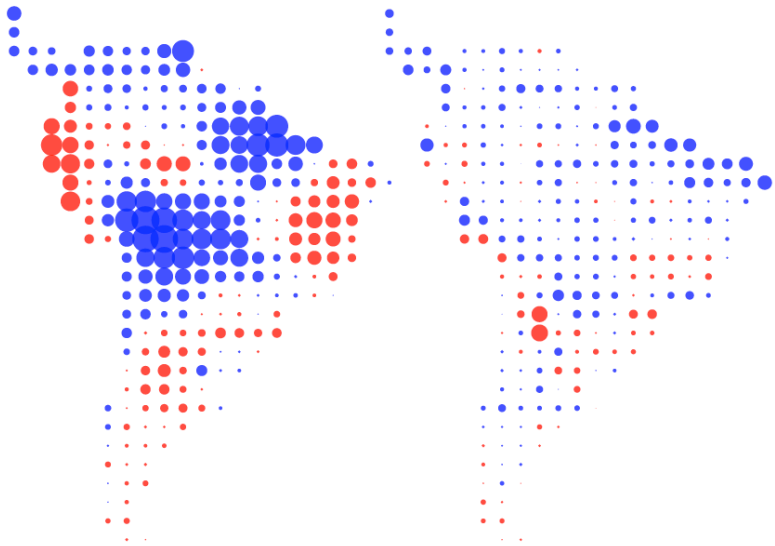

Figure 3. Observed (left) and mean forecast (right) precipitation anomalies (red circles are negative anomalies, blue are positive – size of circle indicates magnitude of anomaly).

4.3. Time series

Time series information is conventionally displayed per location as a graph with time along the *x*-axis. We prototyped some animated maps to show change over time, e.g. the Google Earth based stills in Figure 4 show notable differences between the seasons. We also used SVG to animate Figure 3. SVG supports smooth transitions between time-steps and users liked the aesthetics of this. There is some evidence that smooth transitions can assist in interpretation (Heer and Robertson, 2007), but there is a danger that intermediate stages of the morphing are interpreted as meaningful data points. An interesting side effect of the morphing process for Figure 3's red and blue circles is that the intermediate colour of purple drew attention to changes between positive and negative precipitation anomalies.

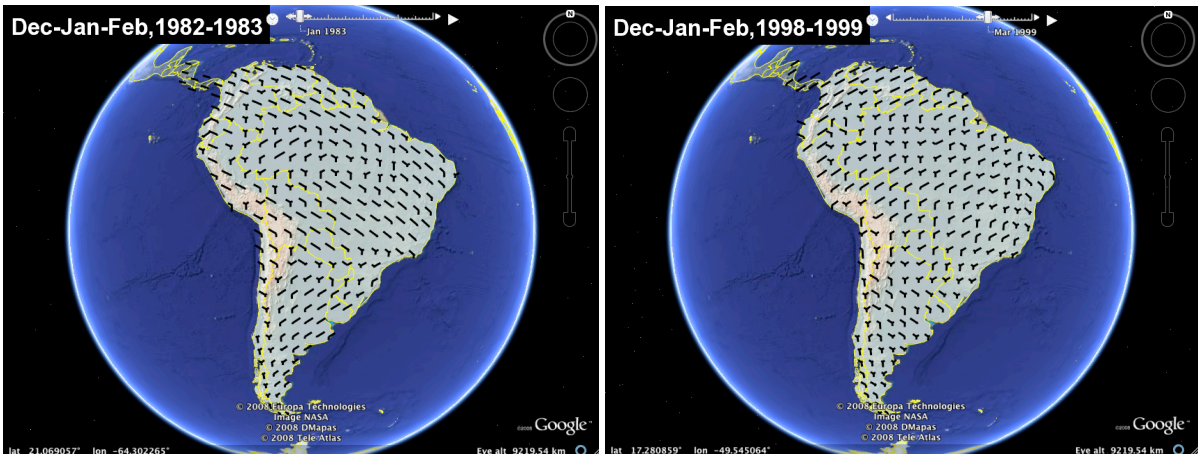

Figure 4. Glyphs showing p1, p2 and p3 values for different seasons.

The use of animation in this way is a common but ineffective technique for trend discovery (Robertson et al., 2008) and interactive techniques may be more appropriate. We rapidly prototyped some ideas in Processing which allows interactive and quite sophisticated prototypes to be created, such as shown in Figure 5 which allows temporal data to be explored spatially and vice versa.

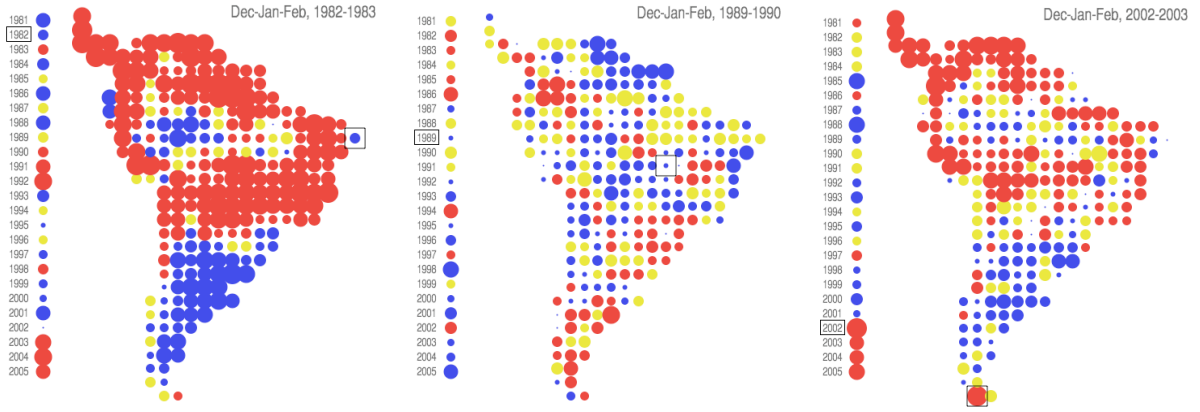

Figure 5. Interactive map that shows the exploration by *grid square* (time-series on the left) or by *season* (map). It also allows seasons to be selected for inclusion in an animation.

4.4. Brier Skill Score

The Brier Skill Score is a measure of the quality of a forecast that applies to each tercile in each grid square over the 25-year period. Transparency is an appropriate means of visually encoding uncertainty (MacEachren, 1992) and is used in Figure 6 to show skill.

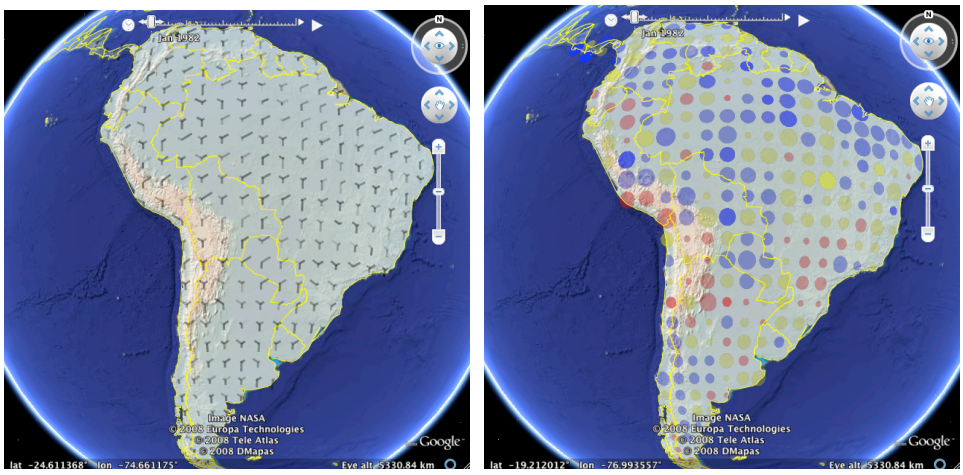

Figure 6. Transparency used to indicate the skill (quality) of the forecast using the Brier Skill Score (BSS). High transparency indicates lower skill.

5. Conclusions and outlook

This pilot demonstrates that cross-disciplinary collaborative work in visualisation is fruitful even where established techniques already exist. All parties involved were exposed to new perspectives and this promoted creative thinking, excitement about the possibilities demonstrated and valuable contributions.

More formal methods are required however. User-centred task-based aims are likely to be core to this activity with long-term workplace-based evaluation. Users initially responded negatively to some of the more complex representations even though they were more information rich. Given time to use them for the tasks for which they were designed may elicit a different response – the Information Visualization community is learning to expect the effective use of sophisticated tools to require training (Shneiderman and Plaisant, 2006). The rapid implementation of ideas as working prototypes facilitated informed feedback and kept all parties engaged. 'Patchwork' data prototypes (Floyd *et al*., 2007) were successful in our pilot and SVG, KML, Processing and R are suitable technologies that allow ideas to be implemented and discussed quickly.

Our formal study design is based on these conclusions and other methods reported in the literature. Creativity is an important part of the design process and was central to our collaboration. Promoting creativity early the design process leads to better solutions (Jones and Maiden, 2005). Our ongoing design incorporates creativity-promoting activities through the RESCUE methodology, a formal task and workplace-based long-term evaluation (Shneiderman and Plaisant, 2006) and patchwork prototyping (Floyd *et al*., 2007). This study will be carried out for specific requirements of specific user groups from the UK MET Office.

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The use of colour was an important part of this study; you can download a colour version of this document from http://www.gicentre.org/papers/gisruk09/climate.pdf

Biographies

Aidan Slingsby is a Willis Research Fellow at City University London; Rachel Lowe is a second-year PhD student at the University of Exeter researching the viability of using seasonal climate forecasts to predict disease risk in Brazil and funded by the Leverhulme network project EUROBRISA; Jason Dykes and Jo Wood are Senior Lecturers in Geographic Information Science at City University London; David Stephenson is Joint Met Office Chair in the Statistical Analysis of Weather and Climate and Director of Exeter Climate Systems at the University of Exeter; and Tim Jupp is a Great Western Research fellow at the University of Exeter, focusing on quantifying uncertainty in the terrestrial carbon cycle (http://www.gwr.ac.uk/).