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Summary

Remit

Our remit is to assess the possible changes in climate during the 21st century that may have an influence on changes in the level of the Caspian Sea. There are two elements to our study:

1. to assess changes in the predictor variables adopted by Rodionov (1994) and others in their statistical induction methods;
2. to assess changes in temperature and precipitation in the upper Volga basin, where approximately 70% of the total streamflow into the Caspian Sea originates.

1. Statistical

We construct three tables, containing:

1. the variables used as predictors;
2. what might be said quantitiatively about these variables on the basis of GCM results, given further time and resources;
3. what may be said qualitatively about these variables.

We conclude that very little may be said about the variables used as predictors by Rodionov (1994) and others without a substantial amount of further work.

Statistical or Dynamical?

However, this inability is not a hindrance to making a realistic assessment of future changes in Caspian Sea levels. The purpose of the first section is to provide an assessment of future changes in particular predictor variables that may be of interest to those using methods of statistical inference to predict changes in Caspian Sea levels. Such methods have been used for many decades: they have proved singularly unsuccessful in practice, and the policies based upon them have proved ill-advised. It is in this context that we introduce climate projections based on dynamical models known as GCMs[1]. In our Annex we provide a more detailed discussion of the history and merits of statistical and dynamical approaches to predicting changes in Caspian Sea levels.

2. Dynamical

In order to provide a full assessment of the possible climate changes in the Volga basin during the 21st century, it is necessary to deal with a number of sources of uncertainty:

- future anthropogenic emissions of greenhouse gases and other pollutants;
- the climate sensitivity[2];
- the regional climate changes accompanying a particular global climate change;
- internal climate variability.

We use a simple climate model to deal with the first two sources, and a number of state-of-the-art GCMs to deal with the second two sources. We combine the simple climate model

[1] GCM denotes either General Circulation Model or Global Climate Model.

[2] The climate sensitivity can be defined as the equilibrium global-mean annual temperature change after a doubling of atmospheric CO_2 concentrations. It indicates the magnitude of the response of the global climate system to perturbation by greenhouse gases.

with the GCMs using pattern scaling. By these means we attempt to include the *limits* to what might reasonably occur.

We find that the Volga basin may be expected to become warmer and wetter during the 21st century as a result of anthropogenic climate change. The GCMs are unanimous in this respect. The precise amounts of change in warmth and precipitation depend on how the uncertainties described above are sampled.

Using the full range of uncertainty in future precipitation changes that we have described, we provide a cursory assessment of the possible changes in Caspian Sea levels that might result. The range of uncertainty is such that at the lower end of the range the changes may be difficult to identify from natural variability in the level of the Caspian Sea, and at the higher end of the range the sustained rates of change approach some of the largest momentary rates of change during the 20th century.

1. Statistical

Aim

We provide a brief assessment – where possible – of future changes in the predictor variables adopted by Rodionov (1994) and others.

Method

1. We **identified the predictor variables** from Rodionov (1994, p147) and from an email from Anna Meshcherscaya (20.12.00). We present these variables in Table 1.
2. We assessed for which of the variables it might be possible to say something about the future, directly on the basis of the **GCM data collected in the DDC**.[3] However, these possibilities could only be realised with more time and resources than are presently available. Our assessment is presented in Table 2.
3. We assessed, in **purely qualitative terms**, what may be said about the future of the variables under radiative forcing. Our assessment is presented in Table 3.

Results

We identified fourteen variables, or sets of variables, seven of which are under investigation by Anna Meshcherscaya (Table 1). However, there are substantial obstacles to obtaining quantitative information from the DDC models concerning these variables (Table 2):

- There are difficulties posed by spatial resolution and varying grid definitions that complicate any assessment of the region-specific variables.
- It is not a trivial matter to translate a classification scheme based on observations into a directly equivalent scheme applicable to different GCMs.
- Tracking algorithms are very difficult to construct and apply.
- Many variables are not available through the DDC.

Because of these difficulties, only a few of the variables might be assessed for the DDC models without a substantial amount of further work being required.

We also restricted our scope to a purely qualitative assessment (Table 3), in which we used the general conclusions about the response to radiative forcing summarised by the IPCC and largely based on GCM results. The dependence of many of the variables on the North Atlantic Oscillation (NAO) is such that not a great deal can be said, even on a qualitative basis, without invoking the NAO.

There is little consensus on the methodology for predicting changes in the NAO, and less consistency between the results, which are heavily model dependent. Decadal predictions of NAO are theoretically possible on the basis of ocean behaviour, but this is some way off yet. The response of NAO within the global response is difficult to predict. Possibly a decreased pole-equator temperature gradient might decrease the zonal flow and decrease the strength or the prevalence of westerlies, but what would this do to the dynamics of NAO? "There appears to be significant model-specific … aspects of changes in blocking activity with increased CO_2" (Kattenberg *et al.*, 1996). This conclusion is not likely to alter much in the forthcoming Third Assessment Report.

[3] The Data Distribution Centre of the Intergovernmental Panel on Climate Change.

Conclusions

Very little may be said about the variables used as predictors by Rodionov (1994) and others without a substantial amount of further work.

Table 1

The variables considered by Rodionov (1994) are as given below. These are a mixture of variables that had already been used as Caspian Sea level predictors, and those that had not been previously examined. We also add (as shaded) the variables Anna Meshcherscaya (AM) is proposing to consider (email, 20.12.00).

label	**predictor variables**	**period**	**season**	**result**	**reference**	**AM**
S	mean annual sunspot numbers	1900-1986	annual	2nd best		using
T^M	Moscow mean annual air T	1900-1986	annual	2nd best		
W,C,E	frequency of Vangengeim-Girs circulation patterns	1900-1986				using
	mean DJF positions and central pressures of Icelandic Low and Azores High	1900-1986	DJF			using
T^K	mean annual T in top 200m of the Kola section of the Barents Sea	1921-1986	annual	best		
I^B	ice cover in the Barents Sea	1900-1981			Privalsky, 1985	using
…I_1	mean winter 500 hPa height anomalies for 4 regions	1947-1986	winter	hopeful		
	mean annual SST in standard Smed areas of the North Atlantic	1900-1970	annual		Privalsky, 1985	
	winter totals of heat flux in the energy-active areas of the North Atlantic	1957-1974	winter		Birman and Pozdnyakova, 1985	
	mean monthly size of the area confined by the polar jet stream in January	1949-1979	Jan		Baidal and Khanzhina, 1986	
	frequency of blocking anticyclones in the N Hemi	1950-1979			Baidal and Khanzhina, 1986	
	winter circulation patterns in the N Atlantic	1901-1970	winter		Kondratovich, 1977	
	horizontal lapse rates (pole-equator) in the N Atl					using
	"the N Atlantic fluctuation indexes"				(are these among the above?)	using
	Vitels anticyclonicity indices (Atlantic-European)				(are these among the above?)	using
	"others if thought applicable and series readily available"					using

Table 2

In this table we assess what it might be possible to say quantitatively about the future of the predictor variables on the basis of GCM data from the DDC. The variables are from Table 1. The variables Anna Meshcherscaya is proposing to use are shaded.

predictor variables	**potential**	**yes/no**
mean annual sunspot numbers	No comment!	no
Moscow mean annual air T	A grid-box value could easily be assigned; downscaling would be more complicated.	yes
frequency of Vangengeim-Girs circulation patterns	All the references for this method of NH circulation pattern classification are in the Russian language. Rodionov (1994) gives a brief account (pp69-71). Classification is not a simple task for GCMs on different grids.	unlikely
mean DJF positions and central pressures of Icelandic Low and Azores High	As stated this seems to require tracking, which is a complex problem. Without tracking, how does one calculate a NAO compatible between different GCMs?	no
mean annual T in top 200m of the Kola section of the Barents Sea	Sea temperatures are required, which are not available from the DDC.	no
ice cover in the Barents Sea	Sea ice data is required, which is not available from the DDC.	no
mean winter 500 hPa height anomalies for 4 regions	Upper air data is required, which is not available from the DDC.	no
mean annual SST in standard Smed areas of the North Atlantic	I am unable to identify “Smed areas”. SST is not available from the DDC, but 1.5m temperature could be used as a proxy if the areas can be identified.	possibly
winter totals of heat flux in the energy-active areas of the North Atlantic	I imagine that heat flux refers to atmosphere-ocean fluxes. However, with only 1.5m air temperature from the DDC these fluxes cannot be calculated.	no
mean monthly size of the area confined by the polar jet stream in January	How does one calculate this from the models? Tracking is probably required. Upper air data is probably required, which is not available from the DDC.	no
winter circulation patterns in the N Atlantic	The best that could be easily done is to calculate a NAO. But even a NAO is not simple to calculate in a compatible manner between different GCMs.	maybe
horizontal lapse rates (pole-equator) in the N Atl	Does this refer to temperature or perhaps pressure? At the surface or at an elevation? Is this a simple gradient?	maybe
“the N Atlantic fluctuation indexes”	What are they?	?
Vitels anticyclonicity indices (Atl.-Euro.)	Only known works of L.A.Vitels are in Russian. Classification probably required.	unlikely
others	n/a	n/a

Table 3

In this table we assess what we may say about the future of the predictor variables on a purely qualitative basis. The variables are from Table 1. The variables Anna Meshcherscaya is proposing to use are shaded.

predictor variables	**Future**	**yes/no**
mean annual sunspot numbers	Non-climatic.	no
Moscow mean annual air T	Continental NH warming → warming.	yes
frequency of Vangengeim-Girs circulation patterns	See discussion of NAO in the Results.	no
mean DJF positions and central pressures of Icelandic Low and Azores High	See discussion of NAO in the Results.	no
mean annual T in top 200m of the Kola section of the Barents Sea	The upper ocean is expected to warm under radiative forcing. However, it is also dependent on regional air-sea interaction, and therefore NAO. See note on NAO.	yes
ice cover in the Barents Sea	Sea ice is expected to greatly diminish under radiative forcing. However, it is also dependent on regional air-sea interaction, and therefore NAO. See note on NAO.	yes
mean winter 500 hPa height anomalies for 4 regions	See discussion of NAO in the Results.	no
mean annual SST in standard Smed areas of the North Atlantic	The general warming is accompanied by regions of cooling, particularly in the N Atlantic, which vary between models. Probably difficult to say anything definite.	no
winter totals of heat flux in the energy-active areas of the North Atlantic	Not sure what to say for this. Probably the locations of the areas change in relation to NAO and ocean dynamics, and the total heat flux must be ocean-dependent.	no
mean monthly size of the area confined by the polar jet stream in January	See discussion of NAO in the Results.	no
winter circulation patterns in the N Atlantic	See discussion of NAO in the Results.	no
horizontal lapse rates (pole-equator) in the N Atl	Arctic expected to warm faster than the equator → decreased temperature gradient.	yes
“the N Atlantic fluctuation indexes”	See discussion of NAO in the Results.	no
Vitels anticyclonicity indices (Atl-Euro.)	See discussion of NAO in the Results.	no
others	n/a	n/a

2. Dynamical

Aim

Approximately 70% of the total streamflow into the Caspian Sea originates in the upper and middle Volga basin, above (and including) the Volga's confluence with the Kama. Therefore, in order to estimate 21st century changes in Caspian Sea levels, it is necessary to estimate 21st century changes in the climate of the Volga basin. In order to do this adequately, a number of sources of uncertainty that must be taken into account:

- future anthropogenic emissions of greenhouse gases and other pollutants;
- the climate sensitivity[4];
- the regional climate changes accompanying a particular global climate change;
- internal climate variability.

GCMs

We use six GCMs to calculate the regional climate responses. These particular models were selected for the following reasons:

- they represent the state-of-the-art;
- there are simulations available from the DDC forced with 21st century increases in greenhouse gases of 1% per annum, that extend to the 2080s;
- the simulations have been regridded by the DDC to a common 2.5° latitude by 3.75° longitude grid.

In terms of structure and resolution, the six GCMs represent a variety of implementations of the basic concept of a fully coupled atmosphere-ocean model, constructed by modelling centres from around the world. For five of the models a single simulation is available. For UK-2 (HadCM2) there is an ensemble of four simulations, forced identically but with different initial conditions. The variety of models enables us to represent the uncertainty due to inter-model differences. The HadCM2 ensemble enables us to represent the uncertainty due to the internal variability of the climate system. The references for these models are given below:

country	**model**	**model reference**	**simulation reference**
Japan	CCSR-NIES	Emori *et al.* (1999)	Emori *et al.* (1999)
Canada	CGCM1	Flato *et al.* (2000)	Boer *et al.* (2000)
Australia	CSIRO2	Gordon and O'Farrell (1997)	Gordon and O'Farrell (1997)
Germany	ECHam4	Roeckner *et al...* (1996)	Roeckner *et al.* (1999)
UK-2	HadCM2	Johns *et al.* (1997)	Mitchell *et al.* (1999)
UK-3	HadCM3	Gordon *et al.* (2000)	Mitchell *et al.* (1998)

For each GCM we calculated the global-mean annual temperature anomaly (°C) for the period 2070-2099 ('the 2080s'), relative to the base period 1960-1989.

[4] The climate sensitivity is the equilibrium global-mean annual temperature change after a doubling of atmospheric CO_2 concentrations. It indicates the magnitude of the response of the global climate system to perturbation by greenhouse gases.

Volga Catchment

The upper and middle Volga basin may be described in terms of a rectangle bordered by the latitude lines at 52 and 60°N, and by the longitude lines at 36 and 60°E. We define an equivalent region on the common grid, which covers all this area, and extends slightly beyond it in each direction; the region is a rectangle of 28 grid-boxes. The regional climate responses described below use the mean of these 28 grid-boxes to represent the Volga Catchment. The 1961-90 climatological normals for this region were derived from the CRU global climate data-set (New *et al.*, 2000), which is available through the DDC:

season	**temperature °C**	**precipitation mm/day**
annual	3.86	1.4
DJF	-8.31	0.98
MAM	4.53	1.04
JJA	17.95	1.94
SON	4.06	1.55

We selected four Volga Catchment climate variables for examination:

- annual temperature,
- annual precipitation,
- winter (DJF) precipitation,
- summer (JJA) precipitation.

We calculated the 2080s anomaly for each variable in each GCM simulation (relative to the 1960-1989 base period). We expressed the temperature anomalies in degrees Celsius, and the precipitation anomalies both in mm/day and as a percentage. By dividing each anomaly by the global-mean temperature anomaly from the same model, we were able to calculate that model's regional climate response to radiative forcing in terms of the regional change per degree of global warming.

Simple Climate Model

It is not feasible to capture all the uncertainties concerning anthropogenic emissions and global climate response using a GCM. Simple climate models are better suited to this task. Therefore we used a simple climate model called MAGICC[5] (Wigley *et al.*, 2000) to estimate global-mean annual temperature changes for the 2080s.

We considered four scenarios of future anthropogenic emissions of greenhouse gases and other pollutants. These four scenarios (labelled A1-B, A2, B1, B2) are four 'markers' among forty equally likely scenarios developed by the IPCC (2000); these four cover almost the entire range of emissions represented by the set of forty scenarios. We also considered three possible values of the climate sensitivity: 1.5°C, 2.5°C, 4.5°C. The largest and smallest values represent the extremes among the range of values the climate sensitivity might take; the middle value is a median estimate.

Using MAGICC we calculated the global-mean annual temperature anomaly for the 2080s, relative to 1990, for each of the twelve combinations of emissions scenario and climate

[5] MAGICC denotes Model for the Assessment of Greenhouse-gas Induced Climate Change.

sensitivity. These twelve combinations are portrayed as a set of twelve graphs in the figures described below.

Volga Catchment Climate Change Estimates

To recap:

- We have estimated the climate response in the Volga Catchment from six GCMs, expressed as changes per degree of global warming.
- We have used a simple climate model to estimate the global warming in the 2080s for twelve combinations of emissions scenario and climate sensitivity.
- We may estimate the 2080s climate changes in the Volga Catchment by scaling the regional responses by the global-means.[6] For each variable, GCM simulation, and combination of emissions and sensitivity, we multiply the regional response by the global warming.

We display the results in a set of figures. The results may be examined by:

- variable (varies between figures and between axes),
- emissions scenario (varies from top to bottom in a figure),
- climate sensitivity (varies from left to right in a figure),
- GCM simulation (varies by symbol within a graph).

The figures are as follows:

1. annual changes in temperature (x-axis, **°C**) and precipitation (y-axis, **%**)
2. seasonal changes in precipitation (**%**): winter (x-axis, DJF) and summer (y-axis, JJA)

The models are unanimous concerning the sign of the changes in annual temperature and precipitation: all simulate a warmer and wetter climate (Figure 1: A1, 1.5). There is also considerable agreement among the models concerning the magnitude of the warming: the inter-model range of responses is approximately half the inter-model mean response. The differences between the temperatures from the various models are probably due to model deficiencies rather than the internal variability of the climate system, because the range within a single model only amounts to a fifth of the inter-model range.

The differences between the models concerning how much wetter the Volga Catchment could become are considerably larger than for temperature: the inter-model range of responses is as large as the inter-model mean response. However, at least half of this range may be explained by the large amount of internal variability in the climate system, rather than by model deficiences.

There is a contrast between summer (JJA) and winter (DJF) precipitation changes in Figure 2 (A1, 1.5). The models agree on an increase in winter precipitation, and the relatively small differences between the models (the inter-model range is less than half the inter-model mean) may be entirely explained by internal variability. However, in summer there is no agreement

[6] A slight difficulty is posed here by the inclusion of sulphate aerosols in the emissions scenarios for which global warming is being estimated, but their exclusion from the calculation of the regional responses in the GCMs. However, Mitchell *et al.* (1999) found that over the earth as a whole, sulphate aerosols had a relatively small effect on the accuracy of this scaling method when the amount of aerosols was relatively small (as is the case in these emissions scenarios). Nonetheless, it is a moot point as to whether this applies to the Volga Catchment, the economic heartland of Russia, with all its pollution problems.

between the models even on the sign of any change. This may be because the internal variability of the climate system is such that both positive and negative responses are possible, or it may be due to model inaccuracies. There is not a great deal of evidence to support the former possibility because the range of responses within a single model only amounts to a third of the inter-model range, but it cannot be ruled out.

The results described above are summarised in Figure 3: each forcing scenario is displayed as a single chart, with three sets of results plotted on the chart, representing the three climate sensitivities (displayed as the diameter of the circle). The point where the blue lines cross is the inter-model[7] median, and the lines themselves are the inter-model ranges.[8] The three parallel red crosses are associated with the same three climate sensitivities: the point where the red lines cross is the intra-model[9] mean, and the lines themselves are the 95% confidence intervals for the intra-model mean.[10]

The uncertainty concerning future anthropogenic emissions and the real climate sensitivity both introduce further uncertainty into the projections of climate change for the Volga Catchment. If we take a single forcing scenario (*e.g.* A1 in Figure 5) we find that the regional changes double in size when the sensitivity changes from 1.5 to 4.5°C. The effect of varying the forcing scenario is much smaller. If we take a single climate sensitivity (*e.g.* 2.5°C in Figure 5) we find that the change from B1 (with the smallest emissions) to A2 (with the strongest emissions) only adds 50% to the regional changes.

Potential Changes in Caspian Sea Level

In the light of these uncertainties we provide a cursory assessment of the effect of the projected precipitation changes on the Caspian Sea level. We note that the projected annual anomalies vary in the range 1.8-20.5%, and that if every projection in Figure 2 is assumed to be equally likely,[11] the expectation value of the annual precipitation anomaly is 8.7%. We recognise the important hydrological influence of the Volga basin, but we do not have the opportunity to represent this except in a fairly crude manner. We allow for this hydrological uncertainty by including three alternative (and equally probable) proportions of the increase in Volga Catchment precipitation to reach the Caspian Sea: 20%, 40%, and 80%.[12] On this basis the changes in the Volga streamflow that arise from changes in precipitation in the Volga Catchment are in the range 0.4-16.4%, with an expectation value of 3.5%. We estimate that

[7] Here, 'inter-model' refers to the five models with single simulations and the first member of the HadCM2 ensemble.
[8] We calculate the median and range because the models do not make up a random sample.
[9] Here, 'intra-model' refers to the four simulations in the HadCM2 ensemble.
[10] The HadCM2 ensemble is a random sample, so it is appropriate to calculate the mean and standard deviation, and from these to infer the range within which there is a 95% probability that the HadCM2 population mean lies.
[11] We only exclude the final three simulations in the HadCM2 ensemble. All other model simulations and all forcing scenarios and climate sensitivities are included.
[12] We selected these proportions as follows. The basin receives precipitation of the order of 500mm per year. We estimate that the upper and middle Volga make up 1,035,000km^2, approximately 75% of the entire area of the basin. We estimate that the same region supplies 225km^3 of water to the Caspian Sea each year. On the basis of these estimates the precipitation that reaches the Caspian Sea amounts to approximately 220mm, or 40% of the annual total. However, this figure is extremely rough, and it is not certain how much of any future increase in precipitation would reach the Caspian Sea. Therefore we consider three possibilities for the proportion of any increase in precipitation that reaches the Caspian Sea: our estimate (40%), and values half (20%) and double (80%) our estimate.

this represents an increase in depth of the Caspian Sea in the range 0.2-9.5cm per year, with an expectation value of 2.0cm per year.[13]

These projected changes should be seen in the context of observed changes in Caspian Sea level over the last 170 years. There is a seasonal cycle in sea level with an amplitude of about 30cm. During the 20th century the rate of change has, on occasion, amounted to 30cm per year or 200cm per decade. On this basis we may assess the practical significance of the changes we have estimated:

- Changes at the lower end of the range (less than 1cm per year) might be difficult to identify from natural variability for many years to come.
- Changes in the middle of the range (1-5cm per year) are noteworthy and represent rises of about a metre over fifty years. This is not exceptional for the last hundred years; greater changes over shorter time periods have been experienced in recent decades, but these had serious ecological and economic impacts. Any greenhouse-gas induced changes might amplify any natural variability in sea level, and would certainly be sustained over more than one 50-year period.
- Changes at the upper end of the range are serious. A steady rise of 5-10cm per year amounts to 50-100cm per decade, a rate that approaches some of the larger changes over the last few decades. Moreover, these changes would not merely be temporary fluctuations, but sustained changes that would be added to with each passing decade.

However, in addition to the general caveats discussed below, there are a number of caveats that must be mentioned that apply to this section in particular:

- Only that part of the Volga basin that makes the largest contribution to the Volga's discharge is included.
- Only a weak assessment is made of the role of the Volga basin in channelling any increases in precipitation to the Caspian Sea.
- No assessment is made of other possible sources of change in the level of the Caspian Sea; possibilities include increased evaporation directly from the Sea in a warmer world, further changes in precipitation elsewhere in the Caspian basin, and changes in amounts of water extracted for economic purposes.

[13] We made this estimate as follows. We estimate that the upper-middle Volga supplies 225km^3 of water to the Caspian Sea every year. The changes in precipitation in the 2080s would increase this figure in the range 0.9 to 36.9km^3 per year, with a mean of 7.9km^3 per year. If we assume that the Caspian Sea has a constant area of 386,400km^2, the precipitation changes represent an increase in depth in the range 0.2 to 9.5cm per year, with a mean of 2.0cm per year.

Caveats

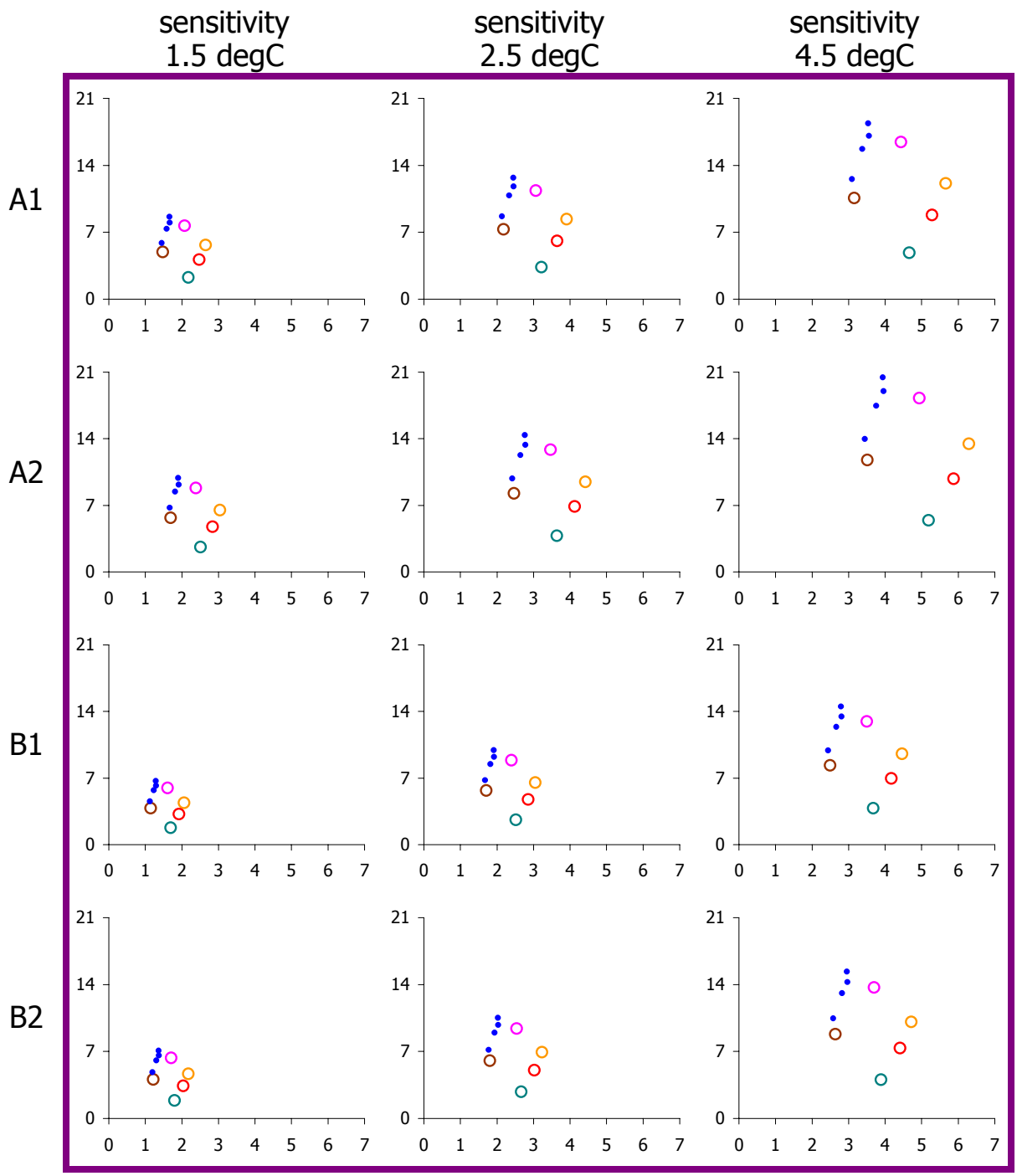
In this assessment of how climate might change in the Volga Catchment over the next hundred years using dynamical models we have been concerned to address the various sources of uncertainty involved. In particular:

- Only three climate sensitivities are included.
- Only four emissions scenarios are included.
- Only six GCMs are included.
- Only a single ensemble is used to estimate internal variability.

However, we emphasise that we have attempted to estimate the *limits* to what might reasonably occur.

Figure 1

Annual temperature and precipitation changes for the 2080s



details

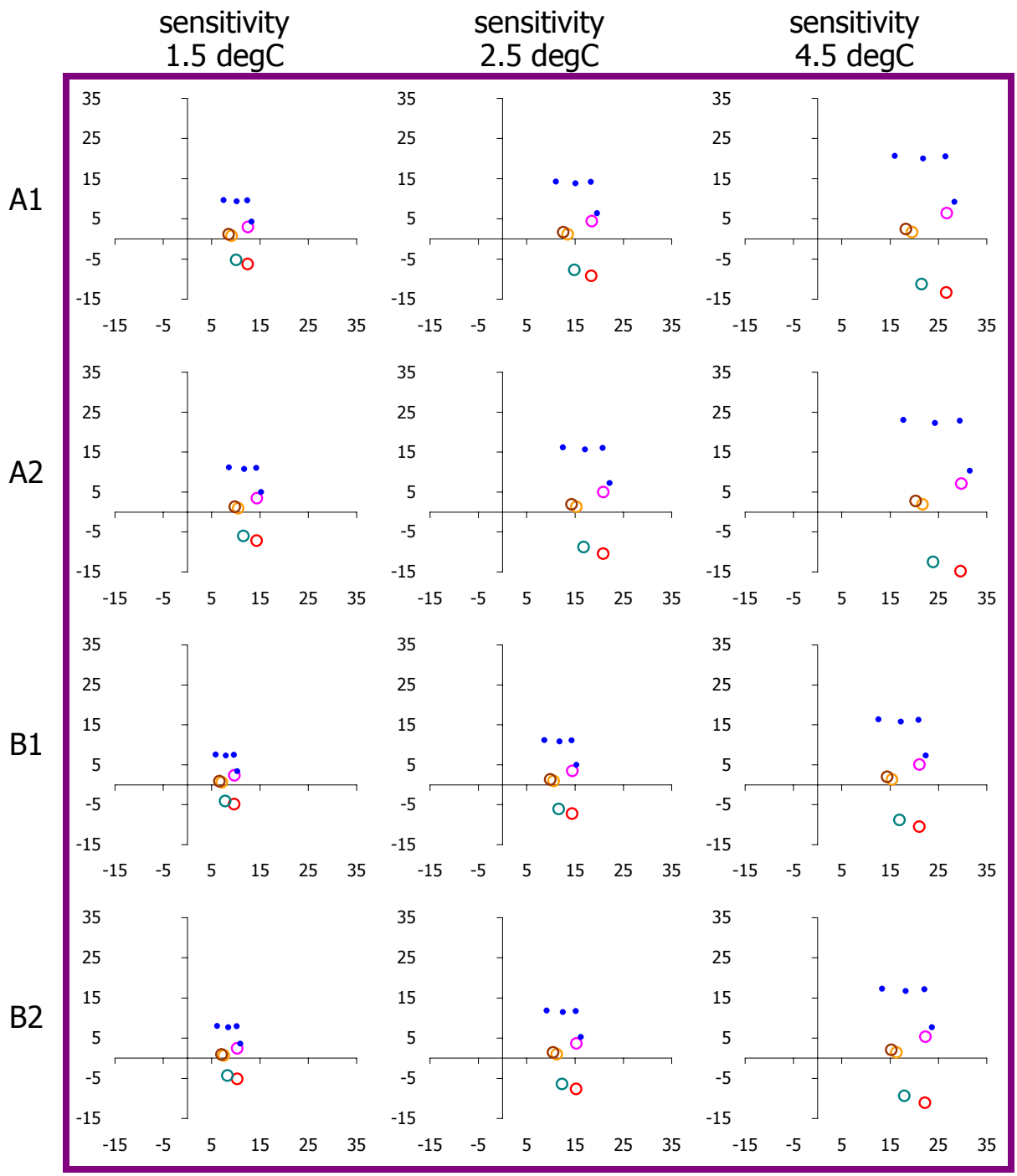
Projected annual anomalies (relative to 1990) in 2080s.
Axes: Temperature (x,degC) and precipitation (y,%).
Upper-middle Volga basin, including the Kama confluence.
Changes for 4 forcing scenarios (A1,A2,B1,B2).
Changes for 3 climate sensitivities (1.5,2.5,4.5).
Changes for six GCMs, including an ensemble (see right).

models

- Japan
- Canada
- Australia
- Germany
- UK-3
- UK-2

Figure 2

Summer and winter precipitation changes for the 2080s



details

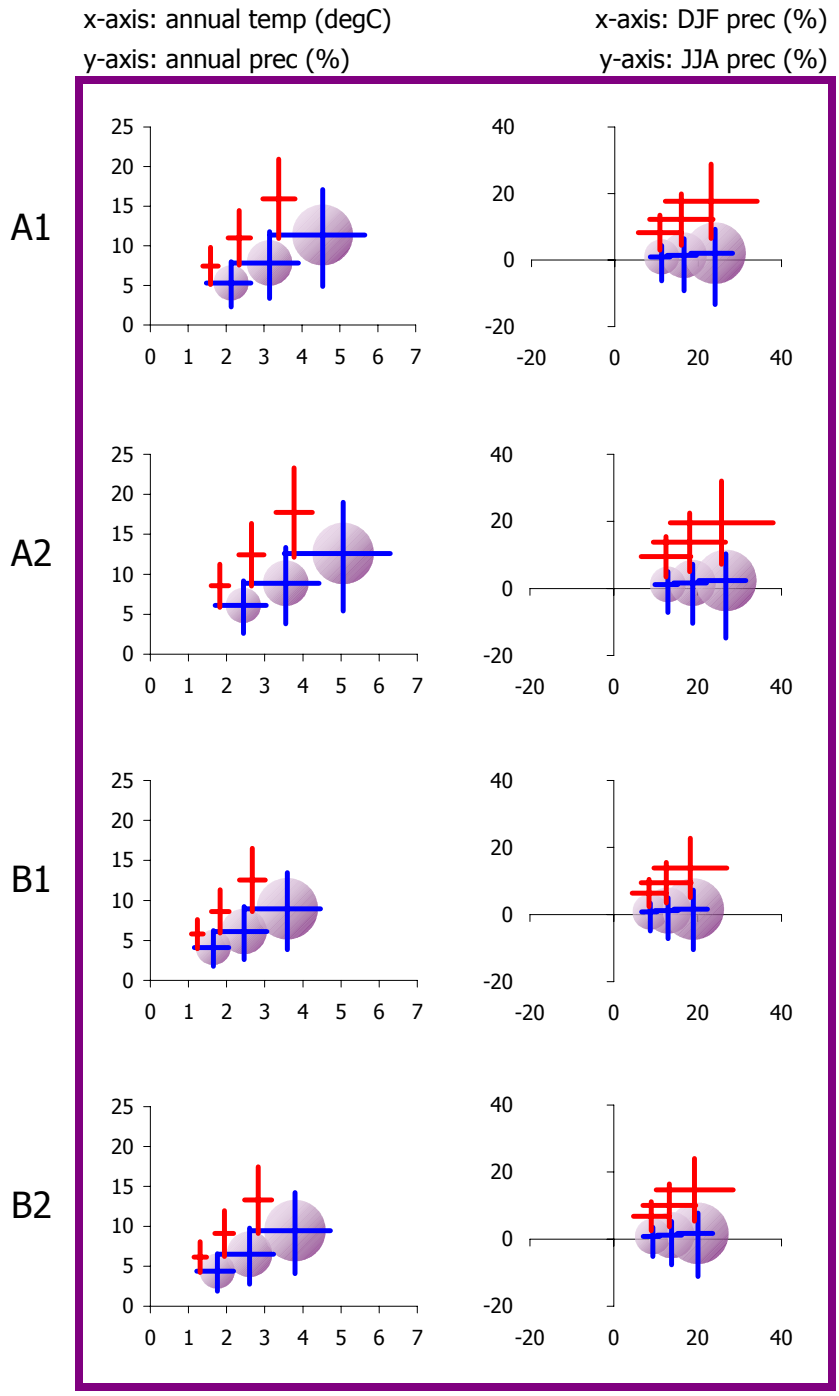
Projected annual anomalies (relative to 1990) in 2080s.
Axes: DJF (x,%) and JJA (y,%) precipitation.
Upper-middle Volga basin, including the Kama confluence.
Changes for 4 forcing scenarios (A1,A2,B1,B2).
Changes for 3 climate sensitivities (1.5,2.5,4.5).
Changes for six GCMs, including an ensemble (see right).

models

- Japan
- Canada
- Australia
- Germany
- UK-3
- UK-2

Figure 3

Summary of 2080s climate changes in the Volga Catchment.



details

Projected anomalies (relative to 1990) in 2080s.
Upper-middle Volga basin, including the Kama confluence.
Changes for 4 forcing scenarios (A1,A2,B1,B2).
Circle diameter is proportional to the climate sensitivity (1.5,2.5,4.5)
Blue lines mark the inter-model ranges, crossing at the medians.
Red lines mark the intra-model 95% confidence limits, crossing at the means.

Annex

Aim

In this annex we assess the role of statistical induction methods in predicting sea level rises in the Caspian Sea, and compare them with dynamical methods.

Background

The Caspian Sea is the world's largest inland body of water both in area and volume. It lies in a large continental depression about 27m below sea level, and since it has no surface outlets its level is a function of the balance between precipitation and evaporation. The economic importance of this region is enormous; one estimate (Ratkovich, 1988) assigned to the Caspian Sea basin one third of the total economic output of the former USSR.

Fluctuations in sea level are one of the most important problems for the Caspian Sea basin; they affect the entire economic system of the region. Consequently the problem of predicting changes in sea level has long been studied, particularly in the former Soviet Union. As we demonstrate below, the history of this scientific endeavour cannot be divorced from the actual changes in sea level that have taken place. Moreover, the policy responses to the scientific predictions have had very costly consequences.

History

- **Millennial** changes in Caspian Sea level (CSL) have been investigated through studies that have encompassed historical references, archaeology, and sedimentary deposits. It has been suggested that levels have varied from +15m (at the time of Ptolemy) to –40m (13th century AD).
- In the **19th century** Lenz (1833) established a systematic basis for observations of the CSL. In the period 1830-1930 the CSL varied within the range of a metre, with an average of –25.8m and peaking at –25.2 in 1882. Relative to the seventy years that followed, this was a period of stability.
- The **1930s** were exceptionally dry, leading to an abrupt drop in the CSL (–26.1m to –27.8m), which had extremely costly effects and gave great impetus to scientific studies of changes in the CSL.
- In the **1950s and 1960s** numerous scientific conferences were held, at which it seemed that Russia was on the verge of finding both the cause of CSL changes, and reliable methods of prediction. These methods of prediction were based on inductive statistics, and ever since these have dominated the Russian scientific endeavour to predict CSL changes:
  (a) Belinsky and Kalinin (1946) correlated the CSL with the **Azores High**. As a result the USSR began issuing regular CSL forecasts five years in advance.
  (b) Girs (1957) claimed that changes in the frequencies of **atmospheric circulation types** in the North Atlantic could explain even *minor* CSL variations, and he emphasised that these were better predictors than even winter precipitation in the Volga basin.
  (c) Eigenson (1957) claimed that **solar activity** was almost deterministic with regard to the CSL.

  On the basis of these predictions and on the basis of the growing water consumption in the basin, predictions were consistently made that the CSL would never rise again. The

USSR believed this prediction (*cf.* the Marxist beliefs in scientific progress and man's ability to mould the natural environment however he likes), and the belief was so strong that many settlements and industrial facilities were moved closer to the shoreline.

- By the **early 1970s** the CSL was dropping to its lowest recorded level, reaching –29m in 1977. The situation was critical for the Caspian Sea fisheries, and dire warnings were given of fishery collapse if the CSL dropped to –31m. The slogan was that "The Caspian Must Be Saved". To 'rescue' the Caspian Sea the 'project of the century' was developed to transfer part of the northern USSR rivers' runoff to the Caspian Sea. However, following the 1977 minimum the CSL began to rise again.
- In the **post-1977 period** the rising CSL was initially assumed to be a temporary phenomenon, but it wasn't. By 1992 the level was back up to –27m. The unexpected rise has caused substantial problems, many arising from the decisions taken on the basis of the prediction that the CSL had peaked and would never rise again. Now the slogan became "We Must Be Saved From The Caspian", and proposed projects included a gigantic dam across the Caspian and the pumping of water to the Aral Sea.
- At the **end of the 21st century** the Russian endeavour to predict the CSL still relies almost exclusively on methods of statistical induction. Rodionov (1994) advocated a complex method of regression using various predictors, concentrating on the variables that were correlated with the CSL in the 1950s and 1960s. The only prediction methods recognised by Mamedov (1999) were based on regression and randomisation; he recognised that forecasts have consistently failed and concluded that there are no reliable methods for predicting CSL changes. Nonetheless Lyatker (2000) believes that the CSL is closely associated with solar activity, that CSL variations may be predicted 10-20 years in advance, and on this basis he predicts that "the average level of the Sea will not increase until at least the year 2010" (p3730).

Discussion

The reasoning of Rodionov (1994), which seems to reflect wider Russian thinking, is that the problem with the pre-1977 predictions were that they concentrated unduly on *regional issues* at the expense of *global climatic processes*. In a sense this reasoning is probably correct, in that the inordinate attention paid to issues such as water demand led to the notorious prediction that the CSL would never rise again. The Russian response is also, in at least some senses, reasonable: they argue that there needs to be a renewed emphasis on global-scale climate.

However, in order to achieve that emphasis they have gone back to the methods of the early post-war years. Consequently Rodionov (1994) uses the same variables from the 1950s and 1960s as predictors, and exercises the same practical mistrust of direct predictions of precipitation for the Caspian Sea basin based on dynamical methods. He recognises that sea levels depend at least partly on global climate changes, and he recognises the anthropogenic influence on the climate system detected using global climate models. Yet because he does not trust the GCMs at sub-global scales, Rodionov (1994) turns to palaeo-climatic analogues. Similarly, the belief among many of those involved in the current Caspian Sea Environmental Programme is that the best approach to CSL prediction for the 21st century is to predict changes in the predictor variables.

Even if the suggested statistical relationships between regional predictor variables and Caspian Sea levels offered reliable predictions in the 20th century (in fact predictions consistently failed), they cannot be relied upon to hold true under conditions of radiative forcing. It is not a solution to this problem to construct statistical relationships between *global*

predictor variables and Caspian Sea levels and apply them to a world experiencing radiative forcing from anthropogenic greenhouse gases. This method neglects the highly complex balance of dynamical and thermodynamical mechanisms on global down to regional scales by which the global climate system responds to radiative forcing, and assumes that regional precipitation will somehow have a direct link to global scale processes. Although GCMs (global climate models) are not as capable of representing changes at regional scales as they are at global scales, nonetheless they represent the best tool available for that task. Moreover, the uncertainty that arises from the frailties of GCMs may be made at least partly explicit by including a number of different GCMs in any assessment.

If we take the approach of using the regional climate changes simulated by multiple GCMs, then we do away with the difficulties we described above. There is no longer a need to use statistical induction to predict the future behaviour of individual, specific variables that are themselves the results of highly complex processes. Rather, we may use the GCM to do the job for which it is most suited, namely to resolve the interlocking dynamical and thermodynamical processes on many different temporal and spatial scales, and thus to represent possible future changes to global and regional climate.

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