UNIVERSITY OF CAMBRIDGE

MATHEMATICAL TRIPOS Part III

Wednesday, 2 June, 2010 9:00 am to 11:00 am

PAPER 69

POLAR OCEANS AND CLIMATE CHANGE

*Attempt no more than **THREE** questions.*

*There are **FOUR** questions in total.*

The questions carry equal weight.

In all questions assume that the latent heat of fusion of ice is $336\,kJ\,kg^{-1}$, and its specific heat is $2.1\,kJ\,kg^{-1}K^{-1}$.

The psu, or practical salinity unit, is equivalent to 1 part per thousand.

STATIONERY REQUIREMENTS
Cover sheet
Treasury Tag
Script paper

SPECIAL REQUIREMENTS
None

You may not start to read the questions printed on the subsequent pages until instructed to do so by the Invigilator.

1

Show that for a simplified "naked planet" Earth, with no atmosphere, the equilibrium temperature T_E averaged over its surface is given by

$$T_E = \left[\frac{(1-a)S}{4\beta}\right]^{\frac{1}{4}}$$

where a is area-averaged albedo, S is solar constant (1366 W m^{-2}) and β is the Stefan-Boltzmann constant (5.67×10^{-8} W m^{-2} K^{-4}). Suppose such an Earth has an ice cover where suddenly 1 million sq km of ice are removed, replacing snow of albedo 0.80 by land or sea of albedo 0.10. Calculate the change that this will produce to the equilibrium temperature of the planet, given that its initial average albedo is 0.3.

Such an area is equivalent to the excess sea ice retreat in summer 2007 compared to the most favourable previous year. Describe the mechanisms that have been proposed for this retreat. You may wish to deal with (i) air temperature changes, (ii) increased heat in the Atlantic layer, (iii) erosion of the cold halocline, (iv) Pacific water inflow, (v) changes in the phase of the Arctic Oscillation, (vi) long-term thinning, (vii) albedo changes, as well as possible combinations of factors that amplify one another.

Describe one major feedback mechanism, other than ice-albedo feedback, whereby the summer retreat of the sea ice can have an impact that increases the rate of global warming.

During the 2007 retreat, 2 m of ice was observed to melt from the ice bottom in the Beaufort Sea during the months July-September. Assuming that all heat required for melting was supplied by the ocean, calculate the average ocean heat flux to the ice bottom, in W m^{-2}, during those months. Compare this figure with what you know about radiative forcing due to global warming. If the ocean area concerned were already ice-free, and the same amount of energy were used to heat the surface water layer (100 m thick), what temperature would it reach by the end of the summer?

2

Distinguish between steric and eustatic contributions to sea level rise, and describe the factors causing each. By estimating the relative magnitudes of the different contributions and changes in them due to global warming, give a qualitative estimate of how the rate of global sea level rise is likely to change during the coming century.

Assuming a mixed layer depth of 200 m, and assuming that the average warming of 1°C in global air temperatures since 1850 is identical to the rise in near-surface water temperatures, estimate the steric rise in global sea level since 1850. Does this figure lead you to conclude that the warming must have reached into deeper parts of the ocean? If so, how and where could this have happened?

If the total run-off from ice sheets and glaciers into the ocean is 600 cu km per year, calculate the annual rise in sea level that results from this input. If the retreat of Arctic sea ice (assumed to have zero salinity) also corresponds to 600 cu km of melt per year, calculate the reduction in global average salinity per year (assuming 4000 m water depth and ocean occupying 70% of planetary surface) due to sea ice retreat. If this is the same as the observed total rate of freshening, how is it possible for net run-off from ice sheets to also occur?

(Assume sea water density is 1025 kg m^{-3}, and that at moderate temperatures a density increase of 1 kg m^{-3} corresponds to a cooling of 5°C or a salinity increase of 1 psu.)

3

Describe the formation mechanisms and geophysical role of long-lived polynyas in (a) the Antarctic, distinguishing between coastal polynyas and polynyas at the edges of ice shelves and (b) the Arctic, focusing on NE Greenland and Smith Sound.

Describe the Pease model of a coastal polynya as a balance between an offshore wind, ice growth and seaward ice advection. Give the basic equations and describe the assumptions made. What are the main factors determining the ultimate width achieved by a polynya and the time needed to achieve it? What changes would occur if there were a substantial rise in air temperature, with no other parameters being altered?

It has been proposed that salt rejection from ice formation in Arctic shelf seas is a cause of the cold halocline phenomenon in the Arctic Ocean, where polar surface water remains at the freezing point with increasing depth whilst increasing in salinity. Given that the Siberian shelf is 100 m deep, and is now ice-free at the beginning of winter, calculate the change in salinity of the shelf water during the first month of winter freezing at a growth rate of 5 cm per day. Given that the Arctic Ocean is one-third shelf, is this mechanism likely to be dominant in maintaining the cold halocline? What other mechanism is possible?

[Assume that the salinity of newly formed ice is 0.3 times the salinity of ambient sea water].

4

"The new religion of global warming ... contains a grain of truth and a mountain of nonsense" (Lord Lawson). In the light of recent expressions of scepticism regarding the reality of anthropogenic global warming, write an essay giving coherent reasons why many of the changes being observed in climate can be ascribed to emissions of climatically active gases, with particular reference to changes being observed in the polar regions. The essay should deal with changes in the ice, ocean and atmosphere, consider their origin and driving forces, and explain why the magnitude of changes occurring at high latitudes is greater than at low latitudes. Consider also the impacts of polar change on the global environment, and the likely changed state of the planet in 50 and 100 years' time.

END OF PAPER