MSc Exam Question 2006

3d-Var. is a tool to estimate the state of the atmosphere from direct and indirect observations.

(a) What is meant by:

i) A direct observation? [2 mark]
ii) An indirect observation? [2 mark]

(b) 3d-Var. is to be used to estimate the state of the stratosphere (the stratosphere is part of the atmosphere above the 'weather'; it contains the ozone layer). The model consists of global fields of zonal (east/west) and meridional (north/south) winds, (u and v respectively), temperature (T) and ozone gas concentration (χ). In this context, give one example each of:

i) Direct observations. [1 marks]
ii) Indirect observations. [1 marks]

(c) Many Earth observation satellites measure the thermal radiation, R, emitted by the atmosphere to space. A hypothetical satellite is measuring the radiation in a particular frequency band emitted by a single layer of the atmosphere at height z. The layer emits radiance B that depends upon its temperature. On its way to the satellite, this radiation passes vertically through the atmosphere above and is attenuated. A forward model for R is Lambert's Law,

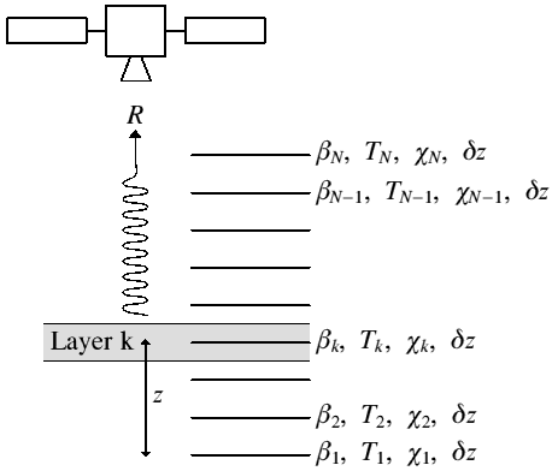
$$R = B(T(z)) \exp\left(- \int_{z'=z}^{\mathrm{TOA}} \mathrm{d}z' \, \beta(z') \right),$$

where 'TOA' means 'top of atmosphere' and $\beta(z')$ determines the degree of attenuation at height z'. $\beta(z')$ depends strongly upon the ozone concentration at height z', $\chi(z')$.

i) What is a forward model and why is a forward model needed in data assimilation? [3 marks]

ii) The measurement of R contains information on which model variables? [3 marks]

iii) Using the diagram below, and by considering a single column of the atmosphere, write down a discretised form of the forward model (you may use the simplest possible integration scheme). Let the model level separation be δz (the same for all levels) and let height z correspond to level number k in this discretization. [4 marks]



iv) Let **H** be the Jacobian matrix for this measurement. In the case of a single measurement, how many rows does **H** have? [1 mark]

v) With help from your answers to parts c(iii) and c(iv), write down **H** for this operator.

[4 marks]

vi) Explain briefly where **H** appears in the 3d-Var. algorithm. [2 marks]

vii) In 3d-Var., can the assimilation only of this radiance observation lead to variables being influenced other than those listed in your answer to c(ii)? [2 marks]