APPLICATIONS OF AND PROBLEMS WITH DATA ASSIMILATION

A sample of scientific and environmental monitoring issues that need data assimilation

- What is the dynamical state of the atmosphere or ocean now / in the future?
- Has the frequency of storms hitting the UK changed in the last few decades?
- How does the Asian summer monsoon change from year to year?
- How does the temperature of the tropopause vary with season?
- What is the distribution of stratospheric ozone?
- How good/bad is the surface air quality around the world?
- What values of certain parameters should be used in our model?
- Is our model biased? Are our observations biased?
- How much gravity wave drag is there in the winter stratosphere?
- What is the geographical distribution of sources of pollutants around the world?
- What is the current state of the thermohaline circulation?
- Where to make observations for maximum forecast accuracy (observation targeting)?

Discuss two applications

- Reanalysis.
- Ozone data assimilation.

Reanalysis

The need for long atmospheric/oceanic data sets

- Researchers need long, consistent, global 4-d data sets for scientific studies.
- Most researchers do not have access to NWP systems to make data sets for specific needs.

Why **re**analysis?

- Over time, models, assimilation systems and available observations change.
- Use observation sets from history and assimilate with one state-of-the-art system.

Reanalysis is good for

- Large-scale variability studies (e.g.)
  - El-Nino, La-Nina, MJO, NAO, monsoons, storm tracks.
- Studies of quantities well modelled and well observed.

Reanalysis is not good for

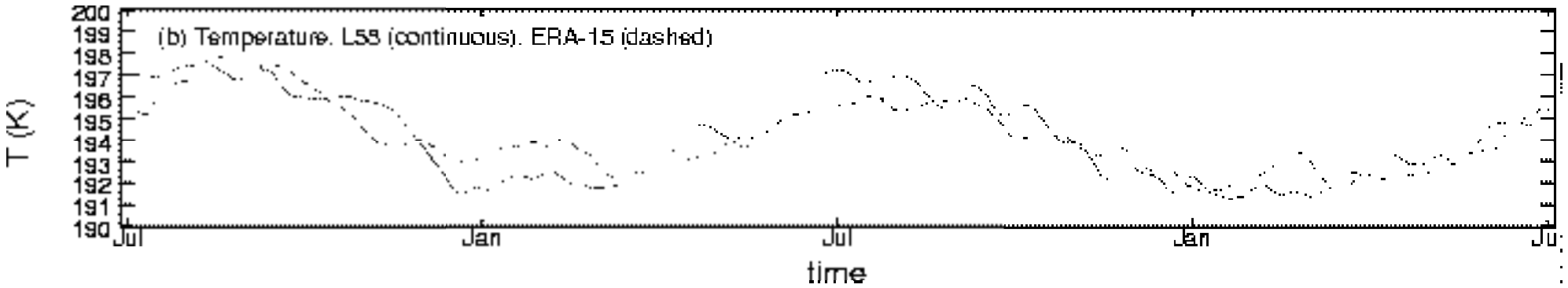
- Trend studies (due to changes in observing systems).
- Studies of poorly observed quantities (e.g.)
  - stratospheric water vapour.
- Studies of derived quantities, not constrained by observations (e.g.)
  - divergent wind, clouds, hydrological cycle, surface fluxes, vertical wind.

Leading reanalysis data sets

- NCEP/DOE - atmosphere.
- ECMWF (ERA-15, ERA-40) - atmosphere.
- NASA/DAO - atmosphere.
- JMA (JRA-25) - atmosphere.
- GODAE - planned ocean reanalysis.

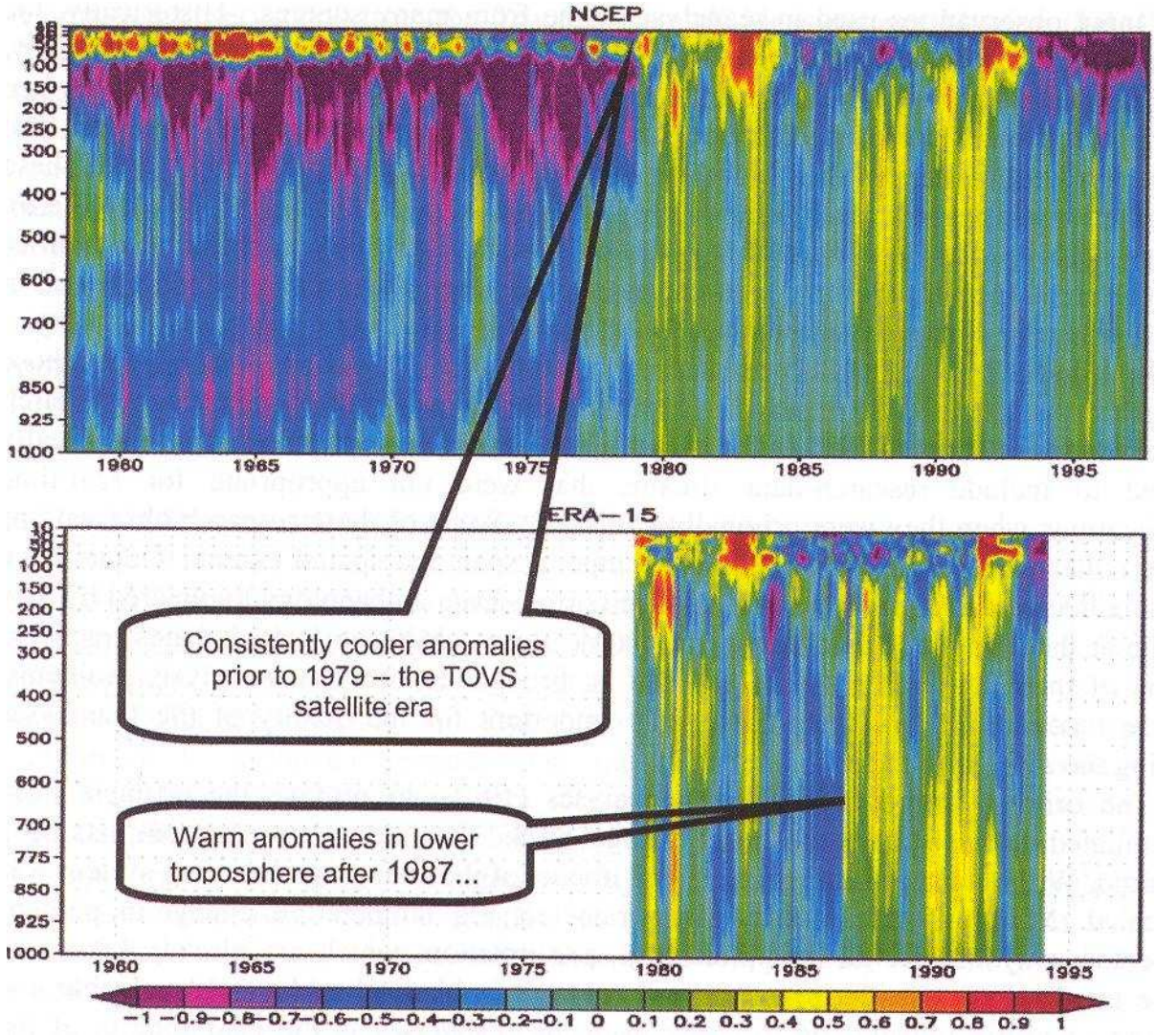
Example reanalysis data

Tropical tropopause temperatures (100 hPa) over a two-year cycle



Bannister et al, 2004

Biases cause problems with reanalysis 1



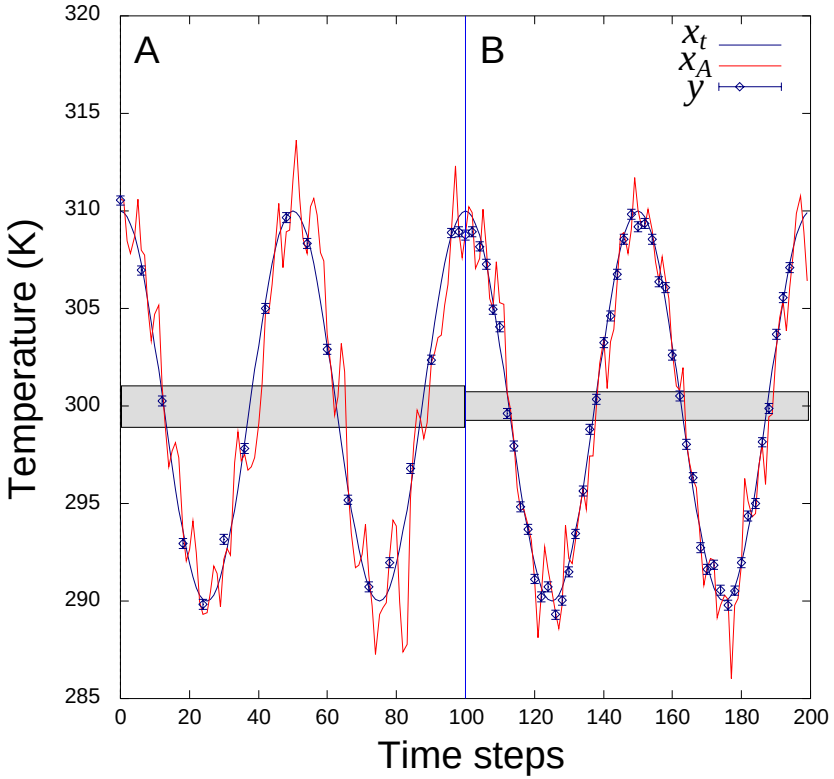
Courtesy, R.Rood (2003)

Reanalysis is inappropriate for climate trend studies

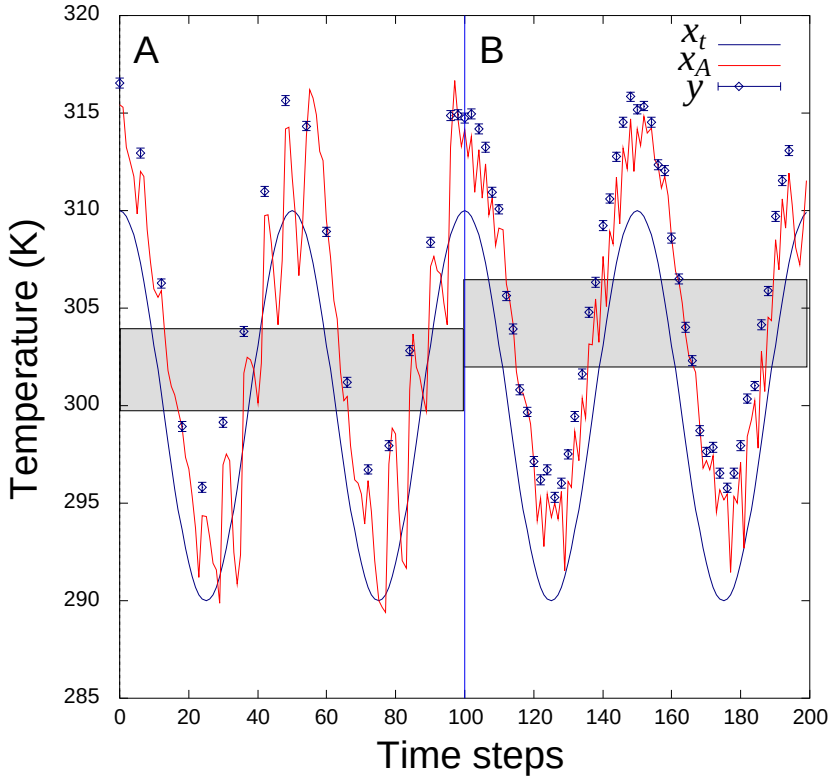
Biases cause problems with reanalysis 2

Consider a jump in frequency of the assimilation of an observation type

If the obs are unbiased, the mean error reduces.



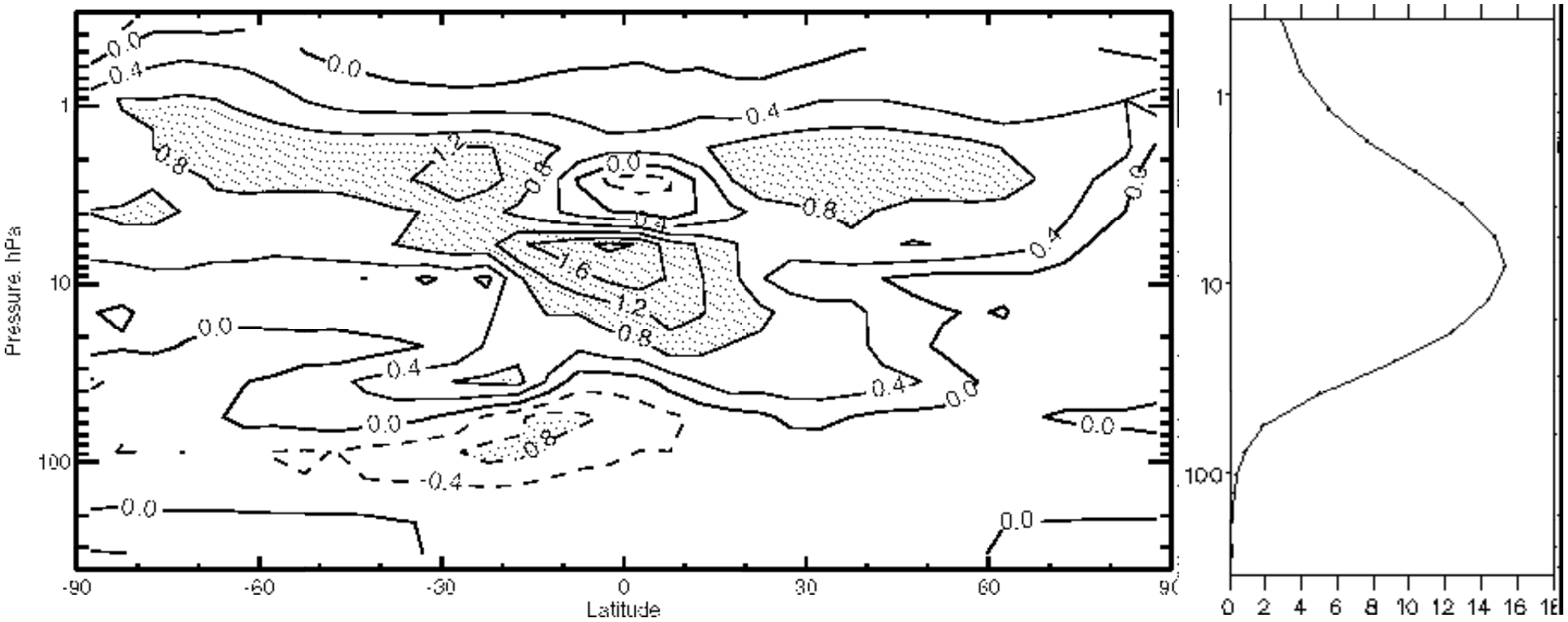
If the obs are biased (6K) , the mean error can increase.



Biases (in observations or models) can lead to artefacts (e.g. apparent trends).

Stratospheric ozone data assimilation and vertical transport

Ozone 'O – F' statistics (left) and vertical tropical ozone profile (right)



O – F courtesy A.J. Geer et al., 2006.

Summary of data assimilation

- Data assimilation is a means of combining evolving model and observational data.
  - Wide range of observations (direct and remotely sensed).
  - Powerful method helps to infer information not directly measured.
  - Huge impact on scientific knowledge and weather forecast capabilities.
- The problem is hard to solve.
  - *Inexact* inverse problem (need to consider error statistics of all quantities).
  - *Under-constrained* inverse problem (not all quantities are constrained by observations - need a-priori information).
  - *Badly conditioned* (numerical minimization problem is 'stiff').
- There are different (but related) modern data assimilation methods.
  - Variational (3d-Var, 4d-Var.).
  - Sequential (optimal interpolation, Kalman filter).
- There are important issues and weaknesses with current data assimilation methods.
  - Suboptimality (error statistics incorrectly specified, non-linearity, etc.).
  - Poor quality information about derived quantities.
  - Reanalysis inappropriate for trend studies.

FURTHER READING

1. Rodgers C.D., 2000, *Inverse methods for atmospheric sounding: theory and practice*, World Scientific Publishing, Singapore.
   - Rigorous introduction to remote sensing methods, error analysis, and data assimilation methods.
2. Schlatter T., 2000, *Variational assimilation of meteorological observations in the lower atmosphere: a tutorial on how it works*, Journal of atmospheric and solar-terrestrial physics 62, pp. 1057-1070.
   - Introduction to variational data assimilation.
3. Daley R., 1996, *Atmospheric Data Analysis*, Cambridge University Press.
   - An advanced book focusing on dynamics, but the early chapters introduce objective analysis and least squares with some interesting historical discussion.
4. Kalnay E., 2003, *Atmospheric Modelling, Data Assimilation and Predictability*, Cambridge University Press.
   - Chapter 5 has a survey of data assimilation methods with simple, physical examples. The book also reviews the state of the art of numerical modelling and some numerical methods.
5. Eyre J., 2000, *Planet Earth seen from space*, in ECMWF seminar proceedings, Exploitation of the new generation of satellite instruments for numerical weather prediction, 4-8 Sept. 2000.
   - A survey of satellites used for operational weather forecasting. Available from the ECMWF web site.
6. Rood R.B., 2003, *Reanalysis*, in Data assimilation for the earth system, R. Swinbank et al. (eds.), Kluwer Academic Publishers.
   - Discussion of the pros and cons of reanalysis. The book covers many other aspects of data assimilation for the Earth system.
7. Bannister R.N., 2001, Elementary 4d-Var. (DARC internal report No. 2), `www.met.rdg.ac.uk/~ross/DARC/DataAssim.html`.
   - Derivation of the 4d-Var. cost function and its derivative.
8. Subset of Reading MSc notes for data assimilation course (available via web address in 7.).
   - Derivation of derivative of cost function and lots of other basic information.