Monitoring the atmosphere and observing system: ERA-40 and GEMS

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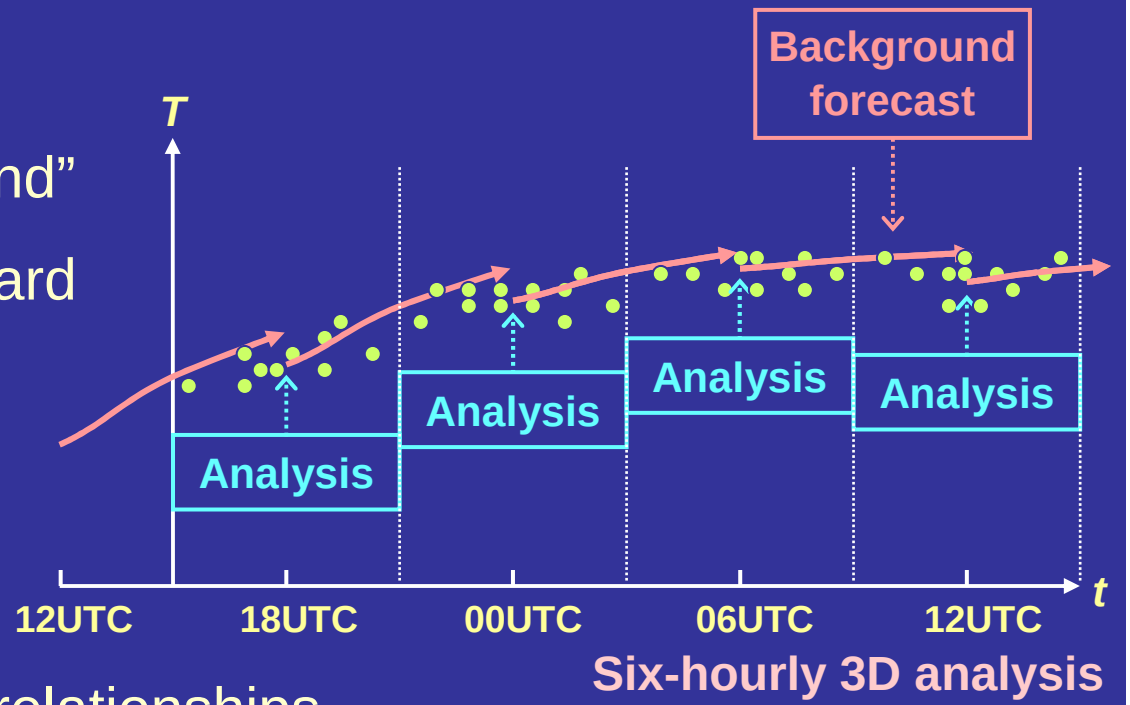
with thanks to all who contributed to ERA-40 and the planning of GEMS

Data assimilation

- **Combines information from**
  - Recent observations
  - A short-range "background" forecast that carries forward information extracted from earlier observations
  - Statistics
  - Dynamical and physical relationships

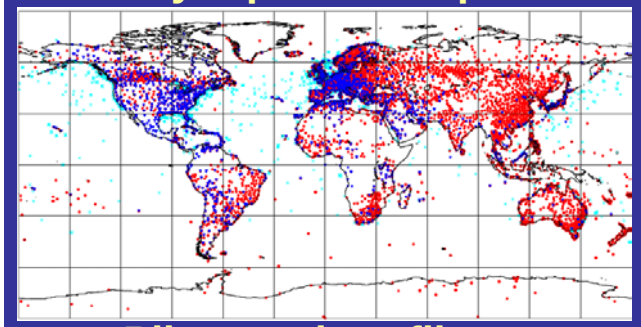


to produce the "most probable" estimate of the state of the atmosphere

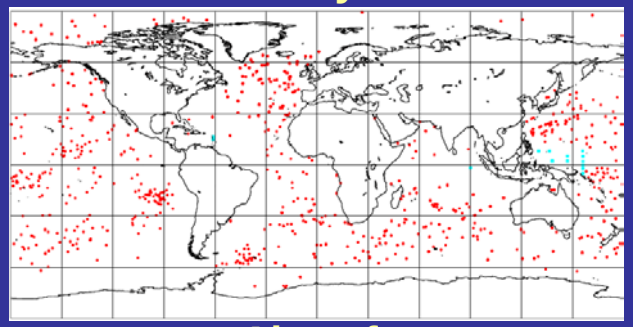
Data assimilation provides:

- Initial states for numerical weather prediction
- A historical record of the state of the atmosphere
- A route to improved determination of atmospheric composition
- Monitoring of the observing system

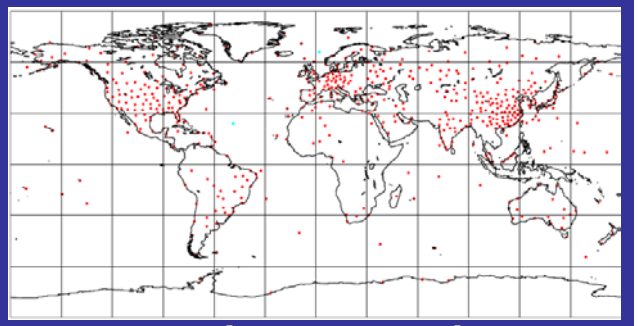
Synops and ships



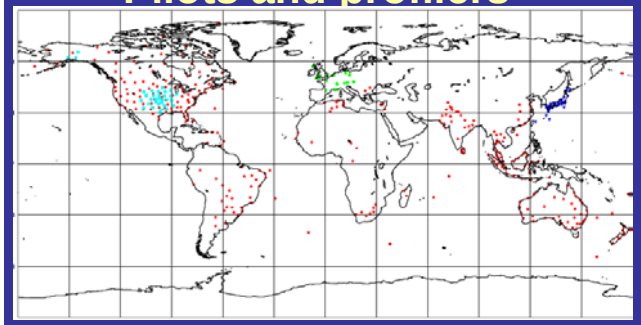
Buoys



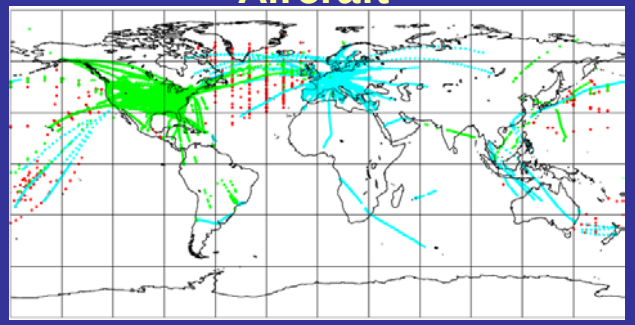
Radiosondes



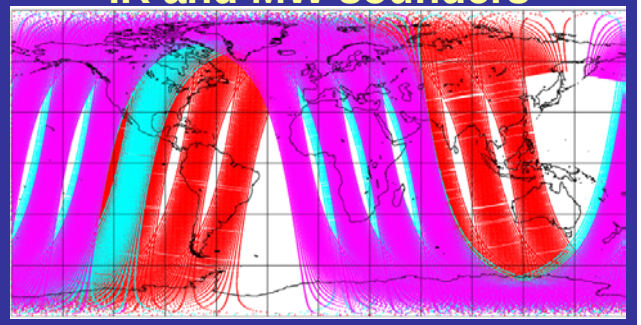
Pilots and profilers



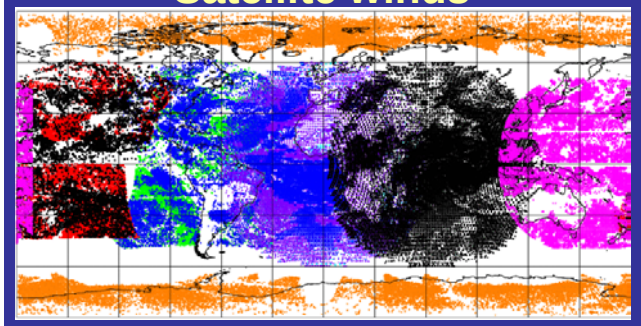
Aircraft



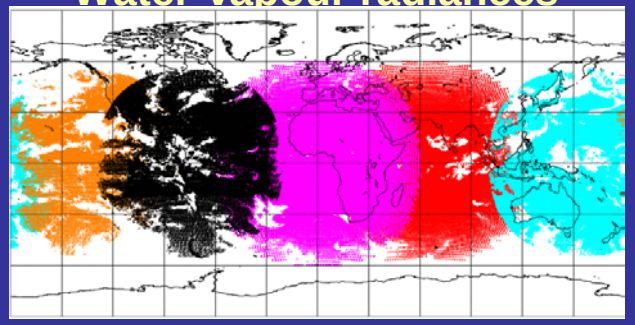
IR and MW sounders



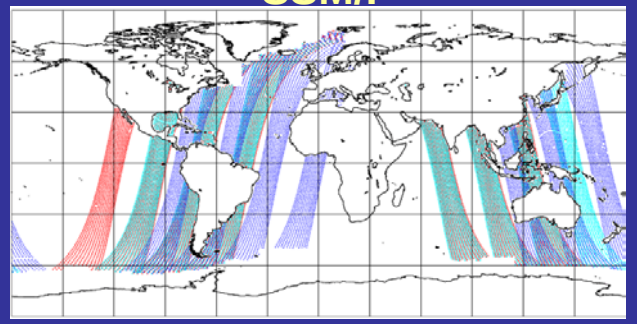
Satellite winds



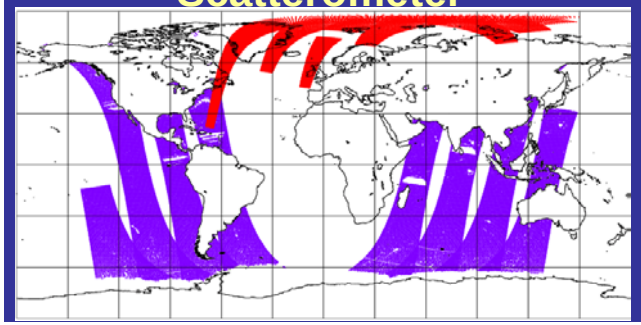
Water-vapour radiances



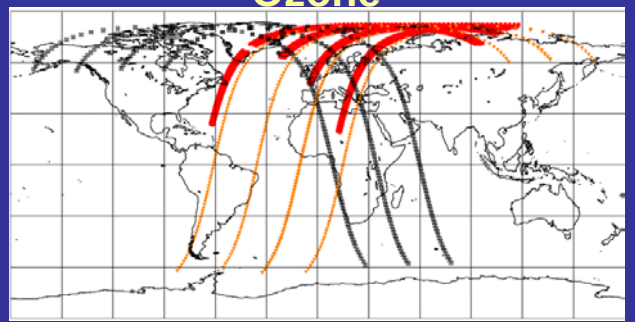
SSM/I



Scatterometer



Ozone



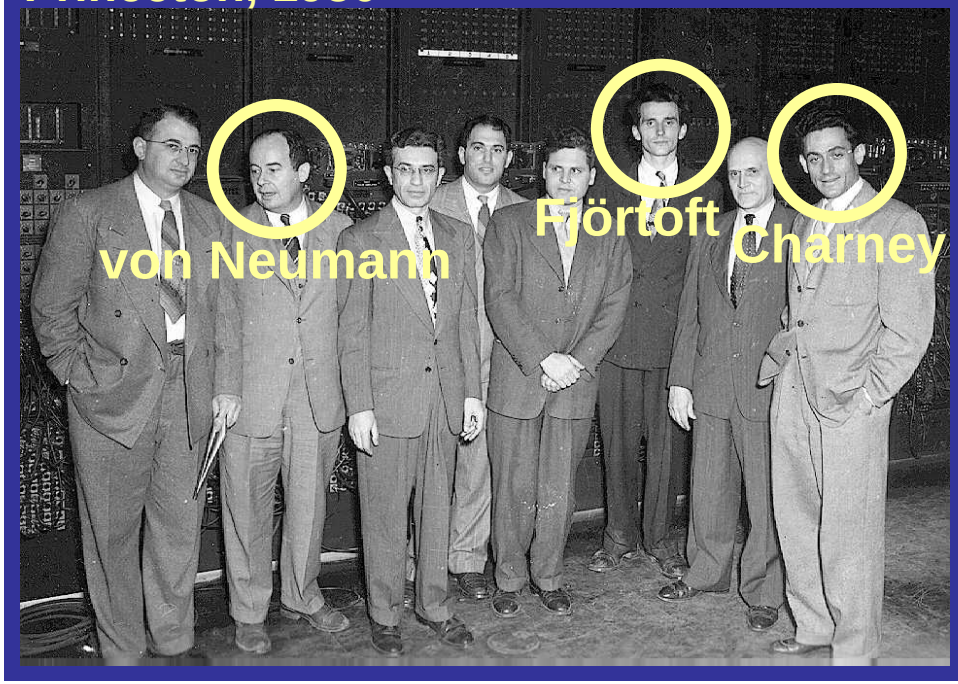
Data coverage

09UTC – 15UTC
5 June 2004

Changes over time

- The observing system has changed substantially since the 1950s
- Data analysis methods and assimilating models, and the computers systems used to run them, have changed substantially over the same period

Princeton, 1950



Reading, 2002

Reanalysis

- **Operational products vary in quality over time due to changes:**
  - in the observing system
  - in the data assimilation systems
  - in the atmosphere itself
- **Reanalysis provides products of more uniform quality by applying a fixed, modern data assimilation system to multi-decadal sets of observations**
- **ERA-40 (September 1957 to August 2002) is the latest reanalysis to be completed**

Principal external sources of support for ERA-40

European Union

US National Center for Atmospheric Research (NCAR)
US National Centers for Environmental Prediction (NCEP)

Fujitsu Ltd

EUMETSAT

Japan Meteorological Agency
Chinese Academy of Sciences
PCMDI, USA

World Climate Research Programme
Global Climate Observing System

And several providers of particular observational datasets

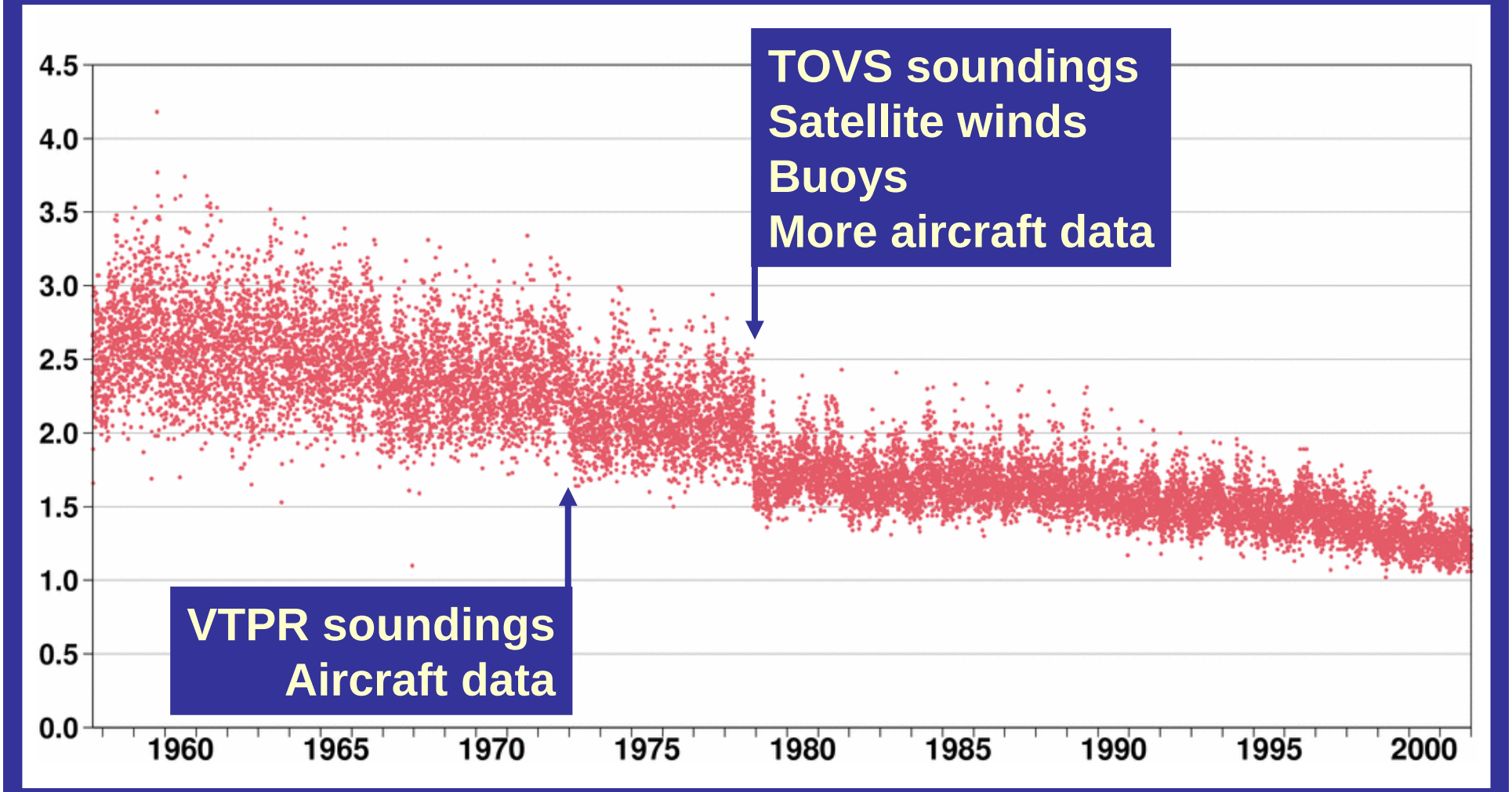
In-situ (“conventional”) observations for ERA-40

- Radiosonde and pilot-balloon soundings 1957 - 2002
- Surface data from land stations and ships 1957 - 2002
- Flight-level data from commercial aircraft 1973 - 2002
- Surface data from ocean buoys 1979 - 2002

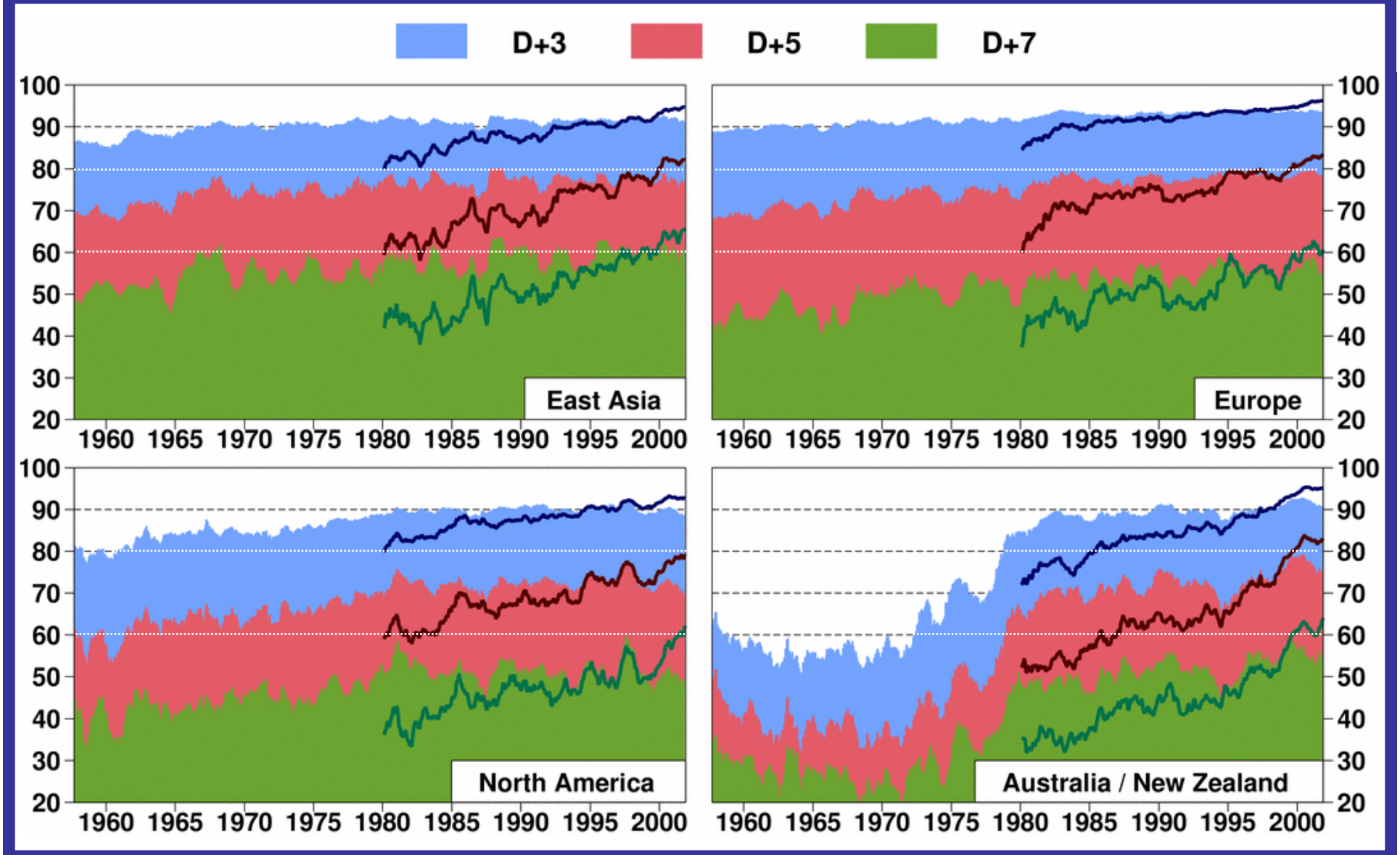
Satellite data for ERA-40

- NOAA VTPR radiances 1973 - 1978
- NOAA TOVS/ATOVS radiances 1979 - 2002
- Winds from geostationary orbit 1979 - 2002
- TOMS/SBUV ozone retrievals 1979 - 2002
- SSM/I radiances 1987 - 2002
- ERS scatterometer & altimeter 1991 - 2002

RMS fit (hPa) of 6h background forecast to SYNOP and SHIP surface-pressure data over the extratropical southern hemisphere



Improvement in medium-range forecast skill

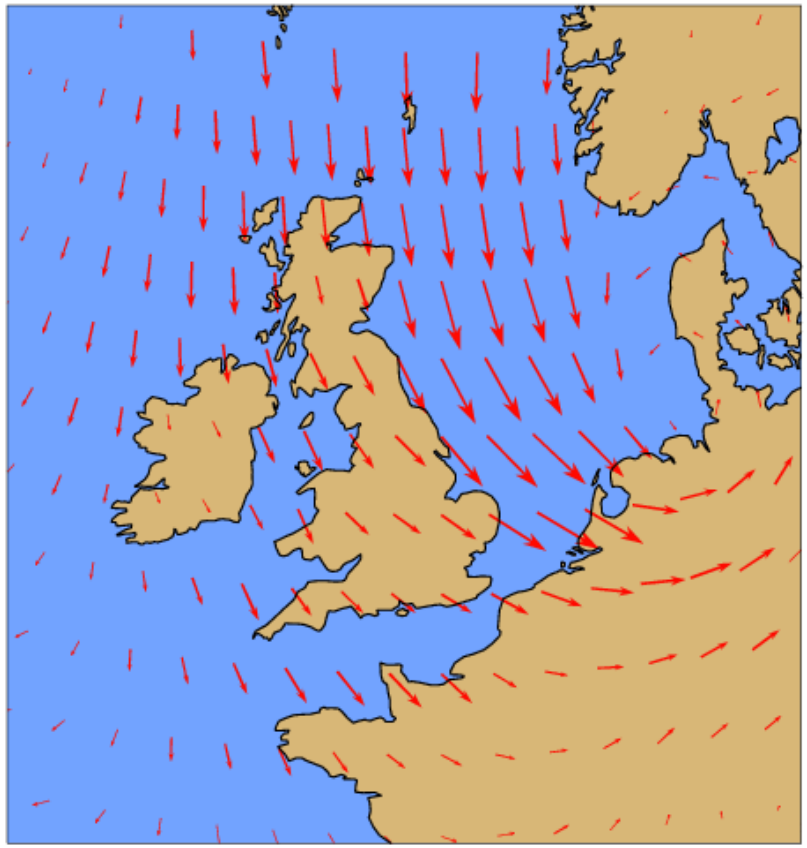


Anomaly correlation (%) of 500hPa ERA-40 height forecasts

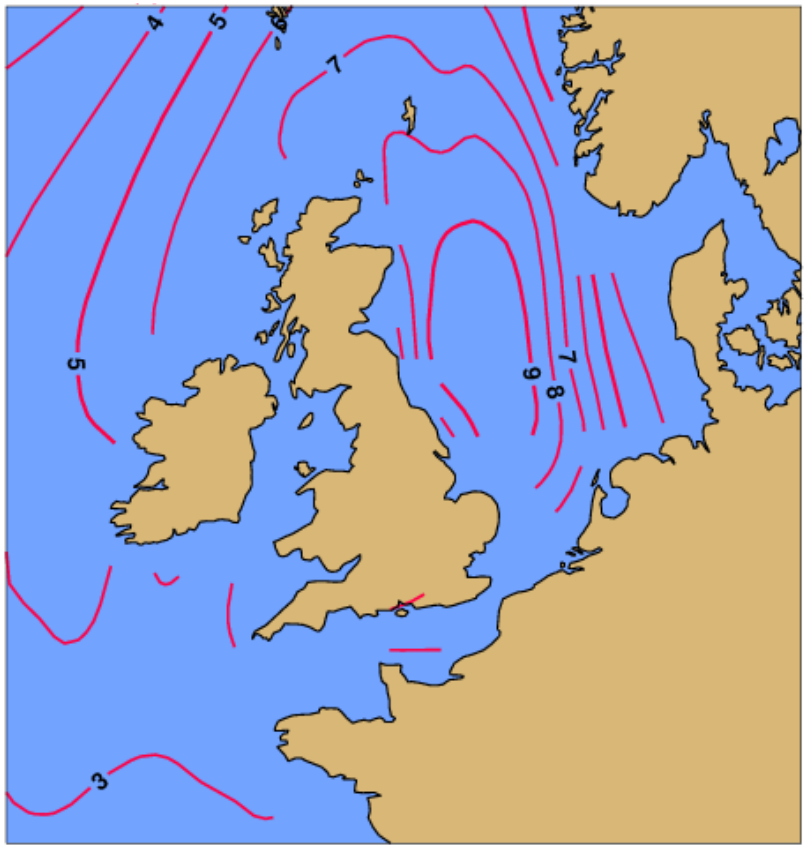
Reanalysis provides a synoptic record

00UTC 1 February 1953

10m wind (→ 25ms^{-1})

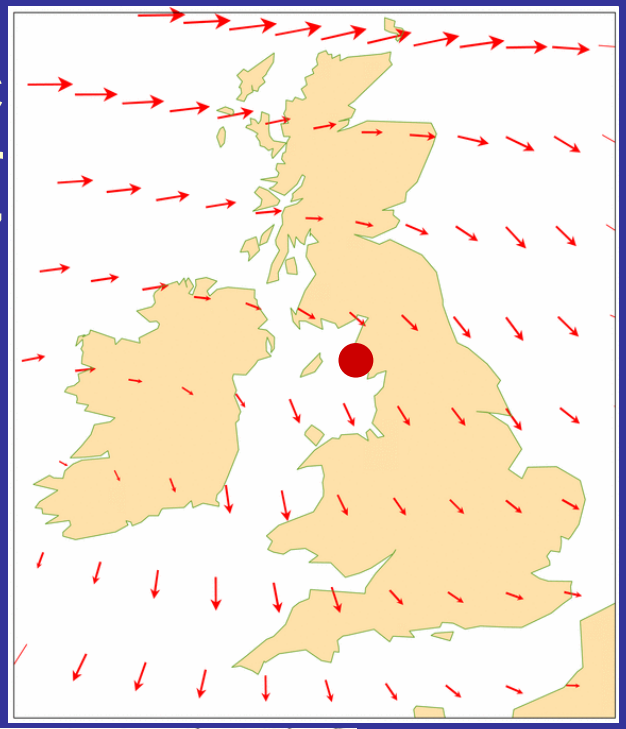


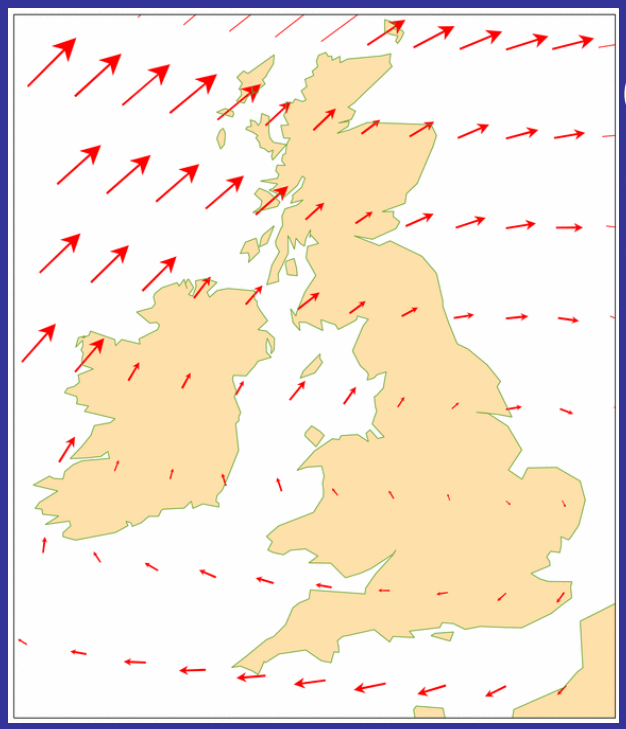
Significant wave height (m)



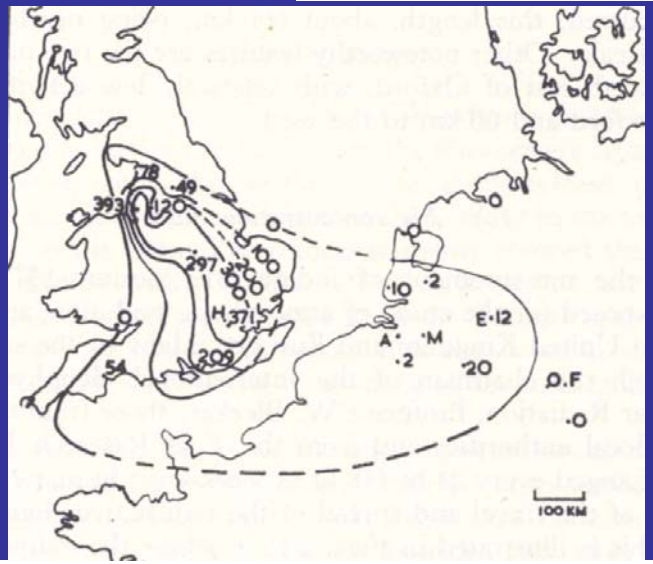
Reanalysis provides a synoptic record

12UTC
11 October
1957



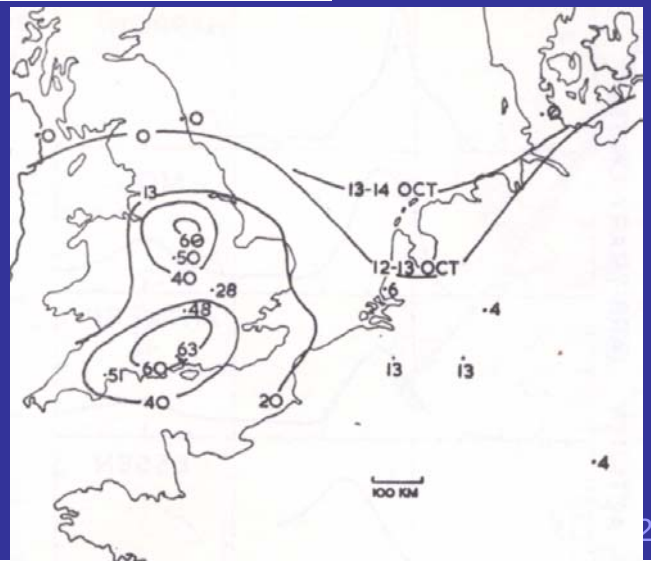


6UTC
12 October
1957

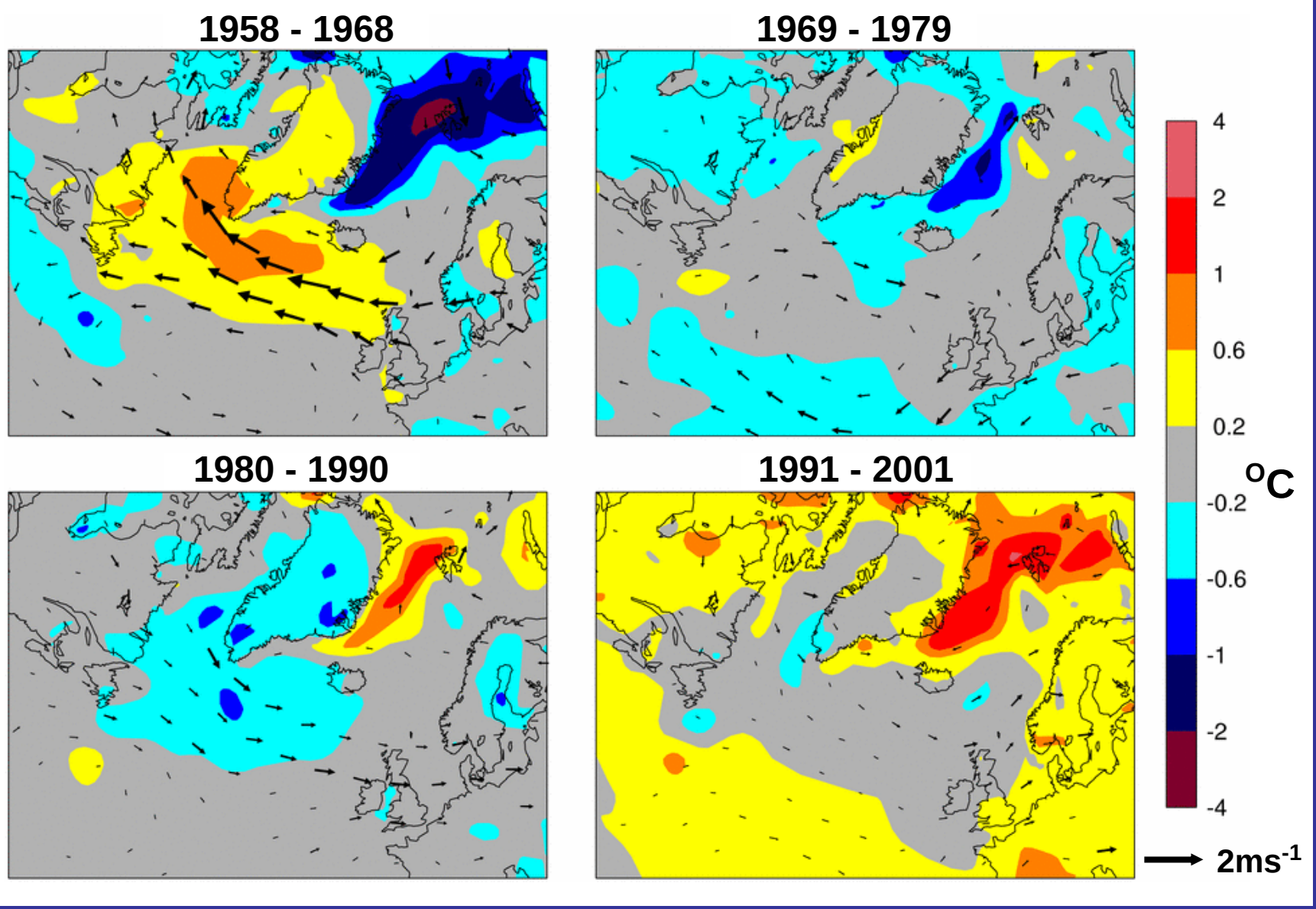


Iodine-131
measurements

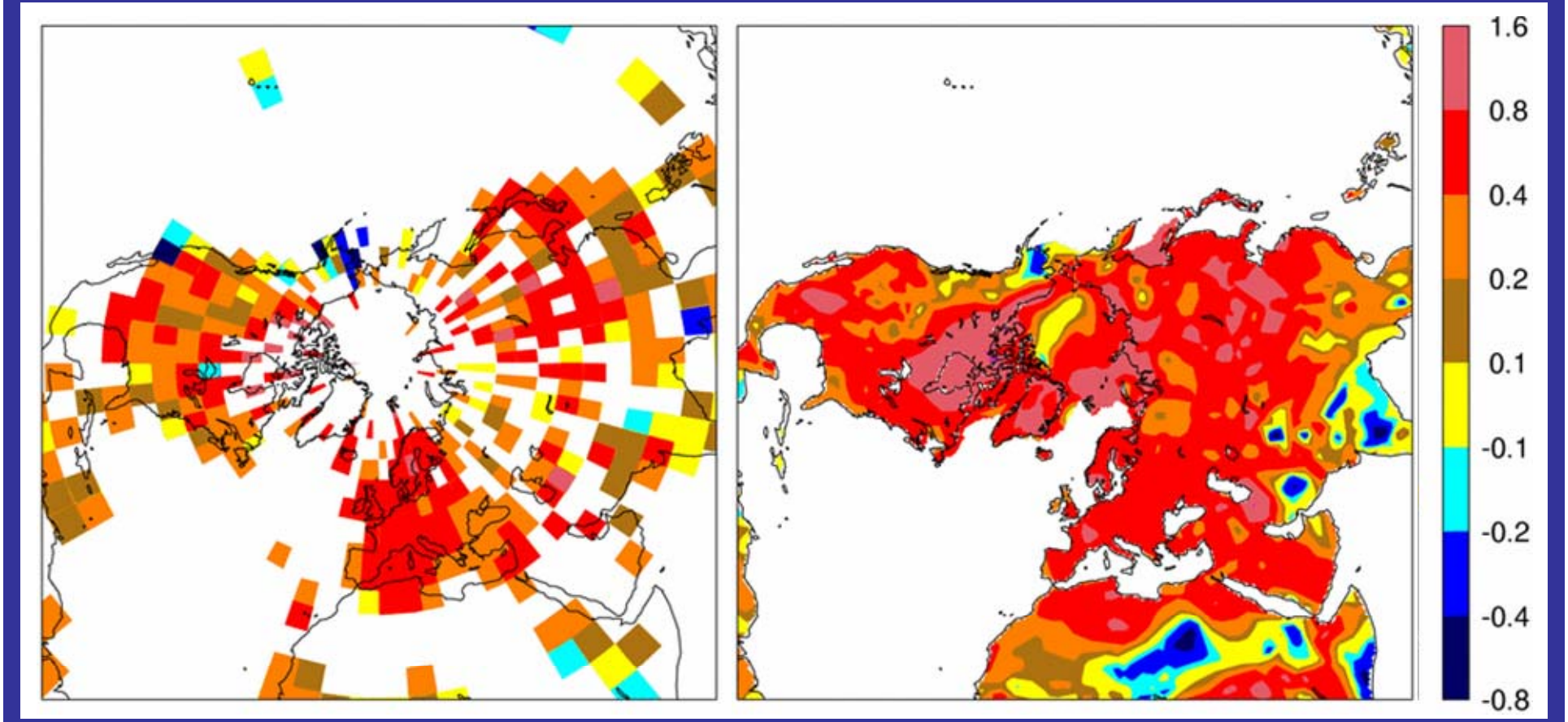
Crabtree(1959)
Quarterly Journal
Royal Met Soc



Anomalies in two-metre temperature and 850hPa wind



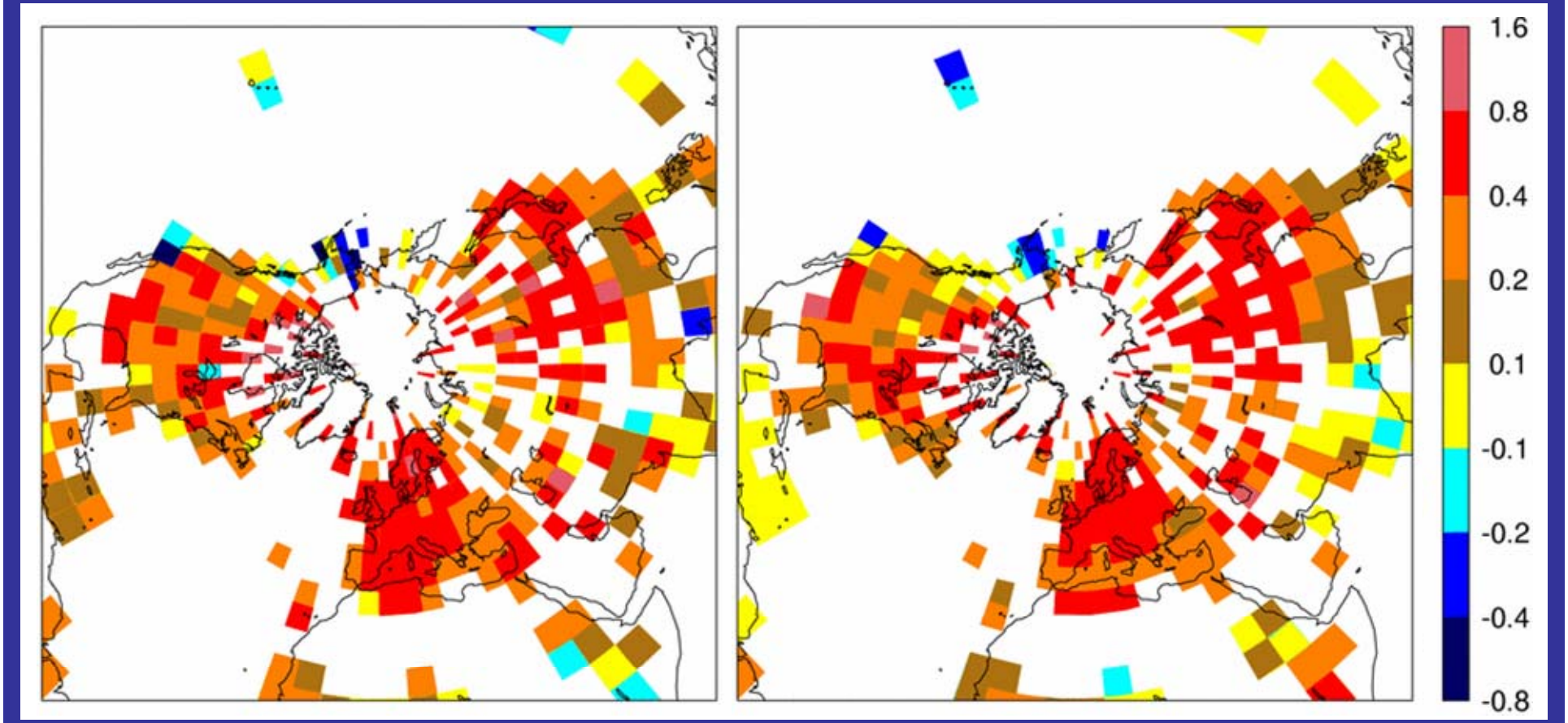
Linear trend in two-metre temperature (ºC/decade) (1979-2001)



Based on monthly station data (Jones and Moberg, 2003)

Based on ERA-40 reanalysis of synoptic data

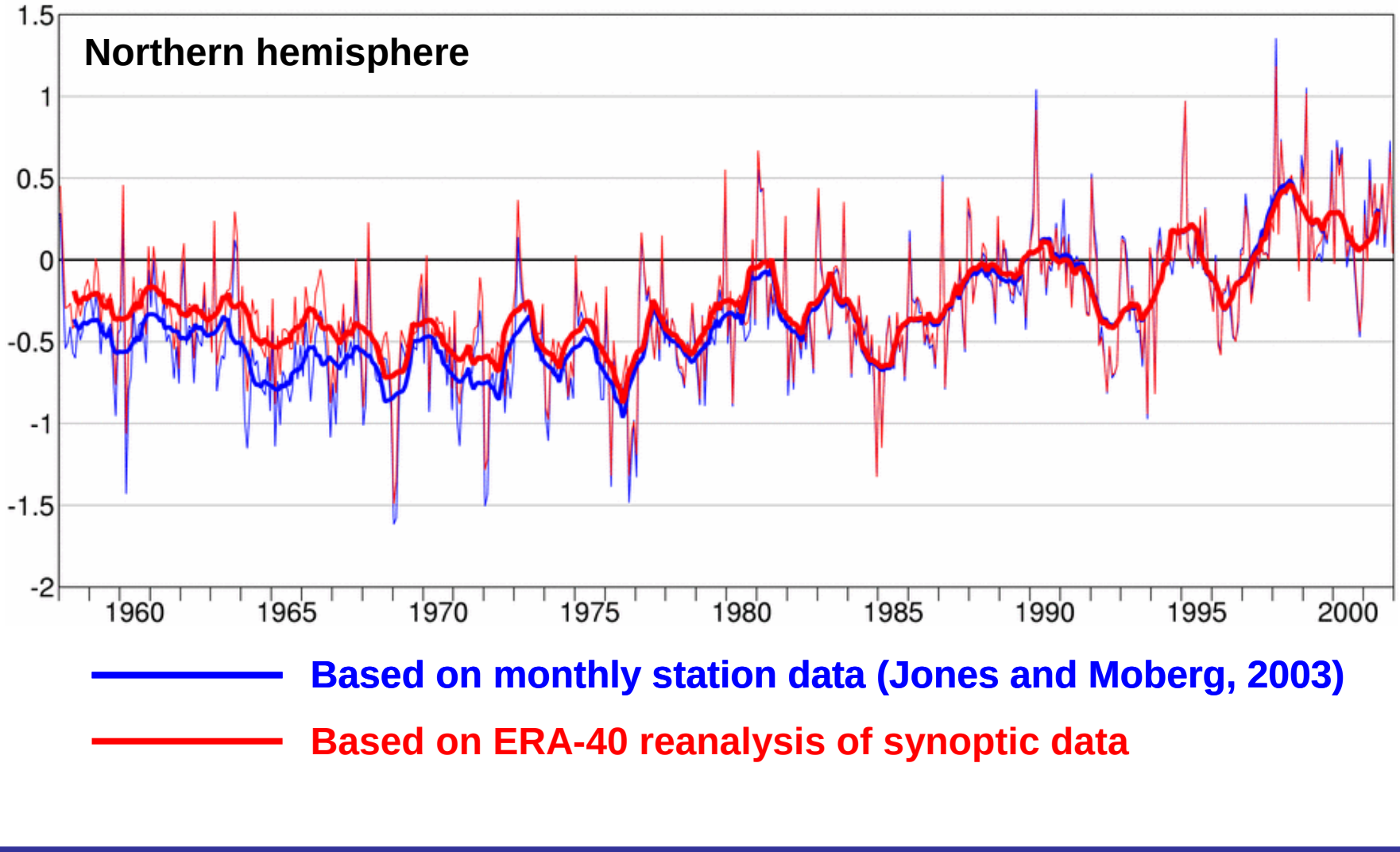
Linear trend in two-metre temperature (ºC/decade) (1979-2001)



Based on monthly station data (Jones and Moberg, 2003)

Based on ERA-40 reanalysis of synoptic data

Comparison of reanalysis and land-station values



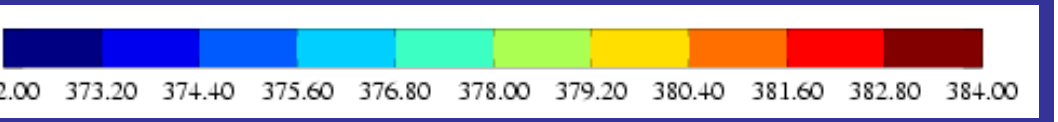
GEMS: Global and regional Earth-system Monitoring using Satellite and in-situ data

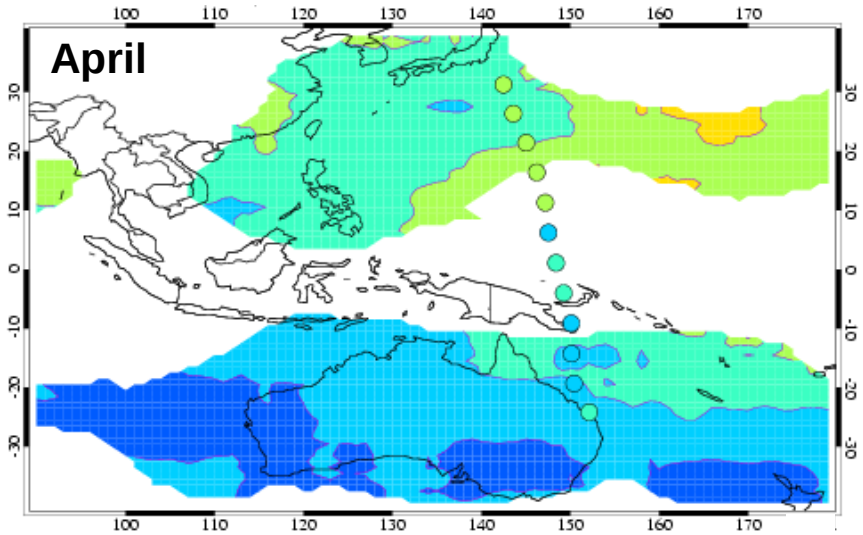
- A multi-partner EC-funded R&D programme to develop:
  - Global modelling and data assimilation for greenhouse gases, reactive gases and aerosols
  - An integrated production system for the above
  - Regional modelling, assimilation and prediction of air quality

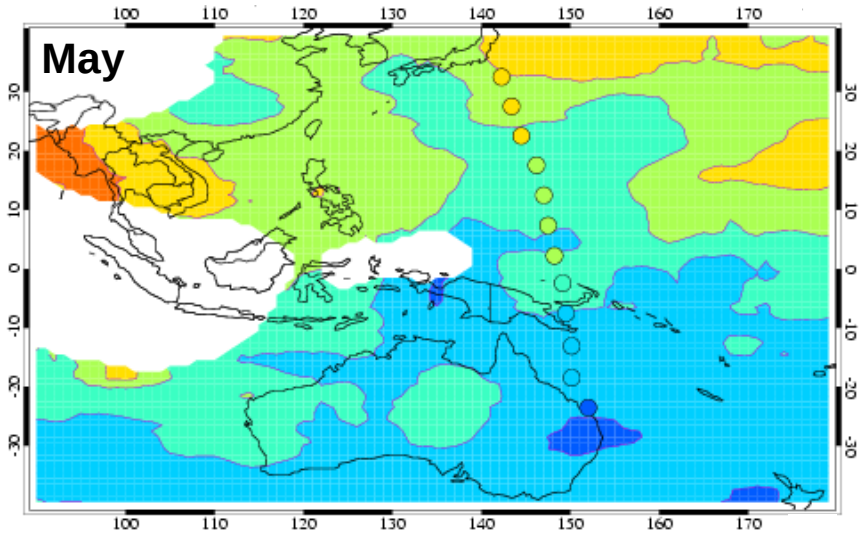
which will enable:

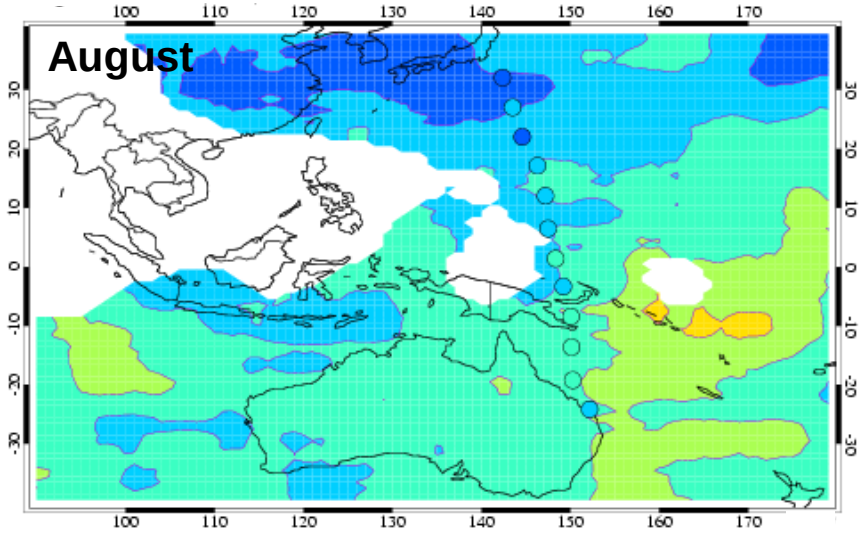
- Daily global monitoring of atmospheric composition
- Better daily regional air quality forecasts
- Estimation of surface fluxes for CO_2 and other species
- More comprehensive reanalysis products

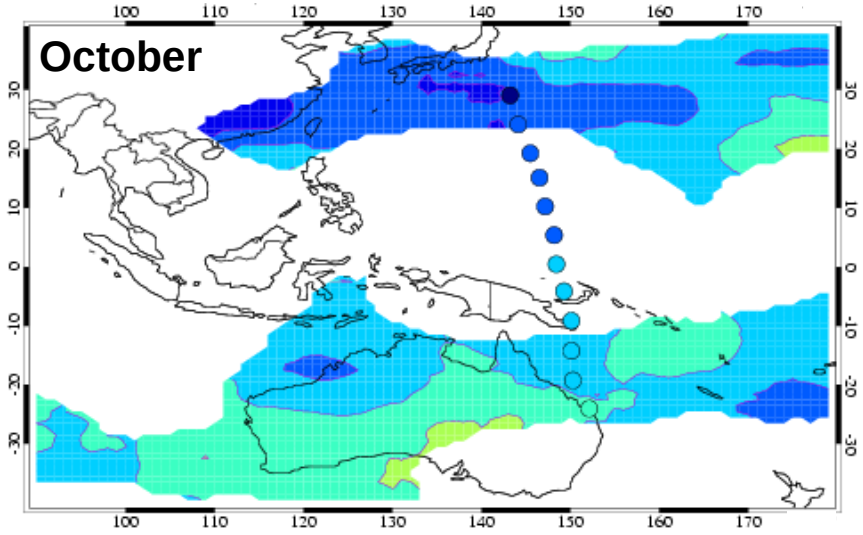
Carbon dioxide





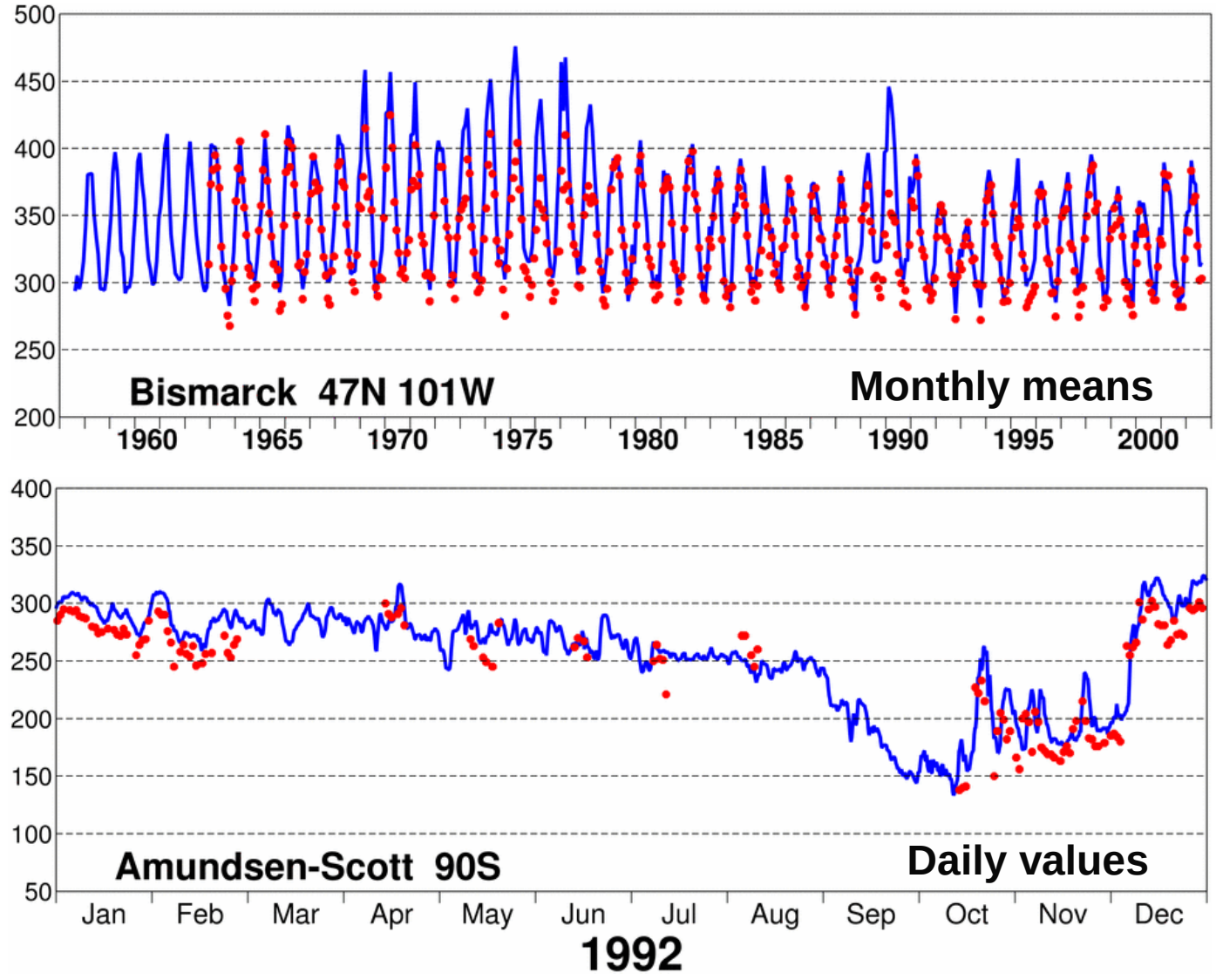






Tropospheric (clear-sky) CO_2 analysis 2003

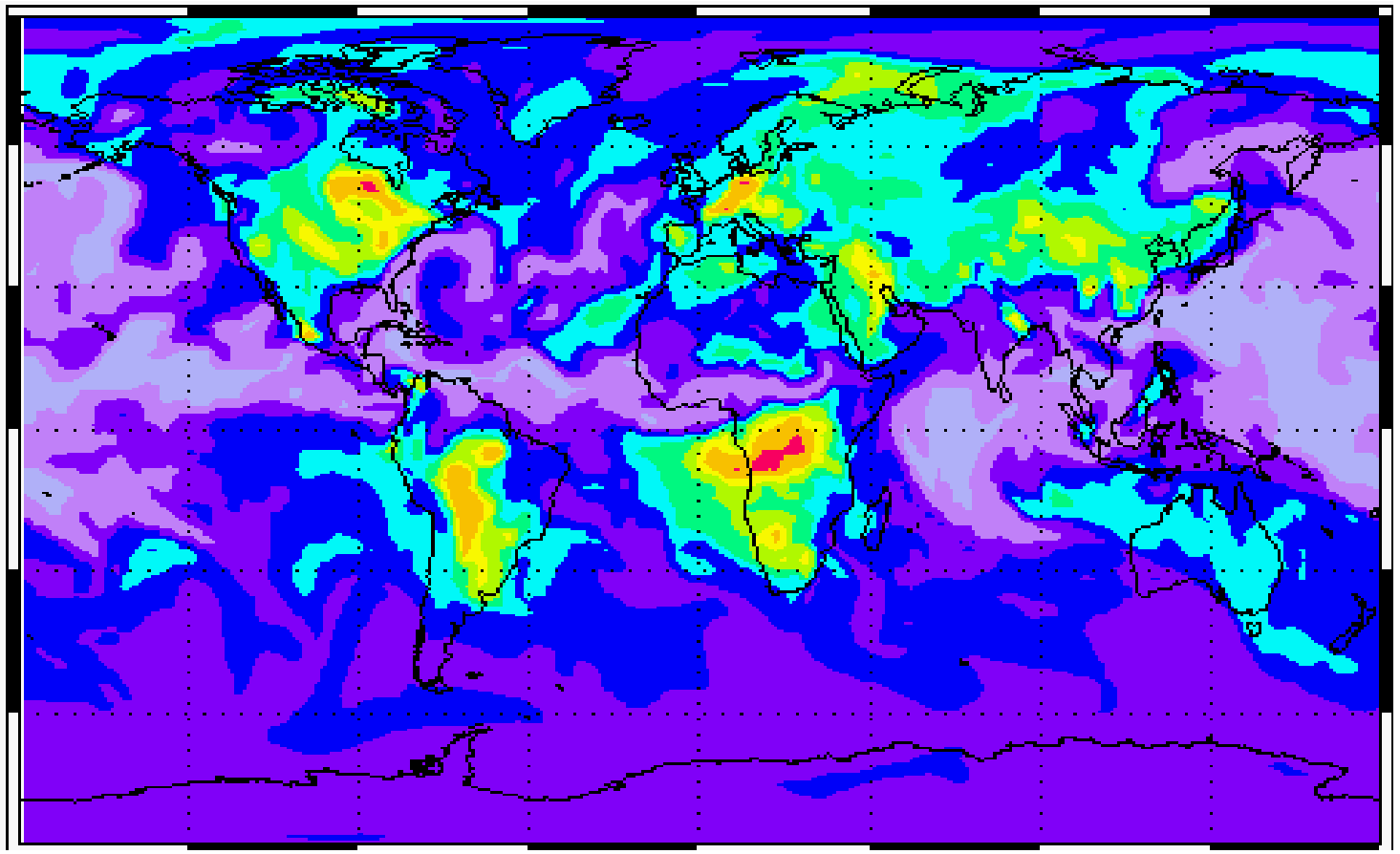
Total ozone



Blue: ERA-40 (TOMS and SBUV data assimilated 1979-1988 and 1991-2002)

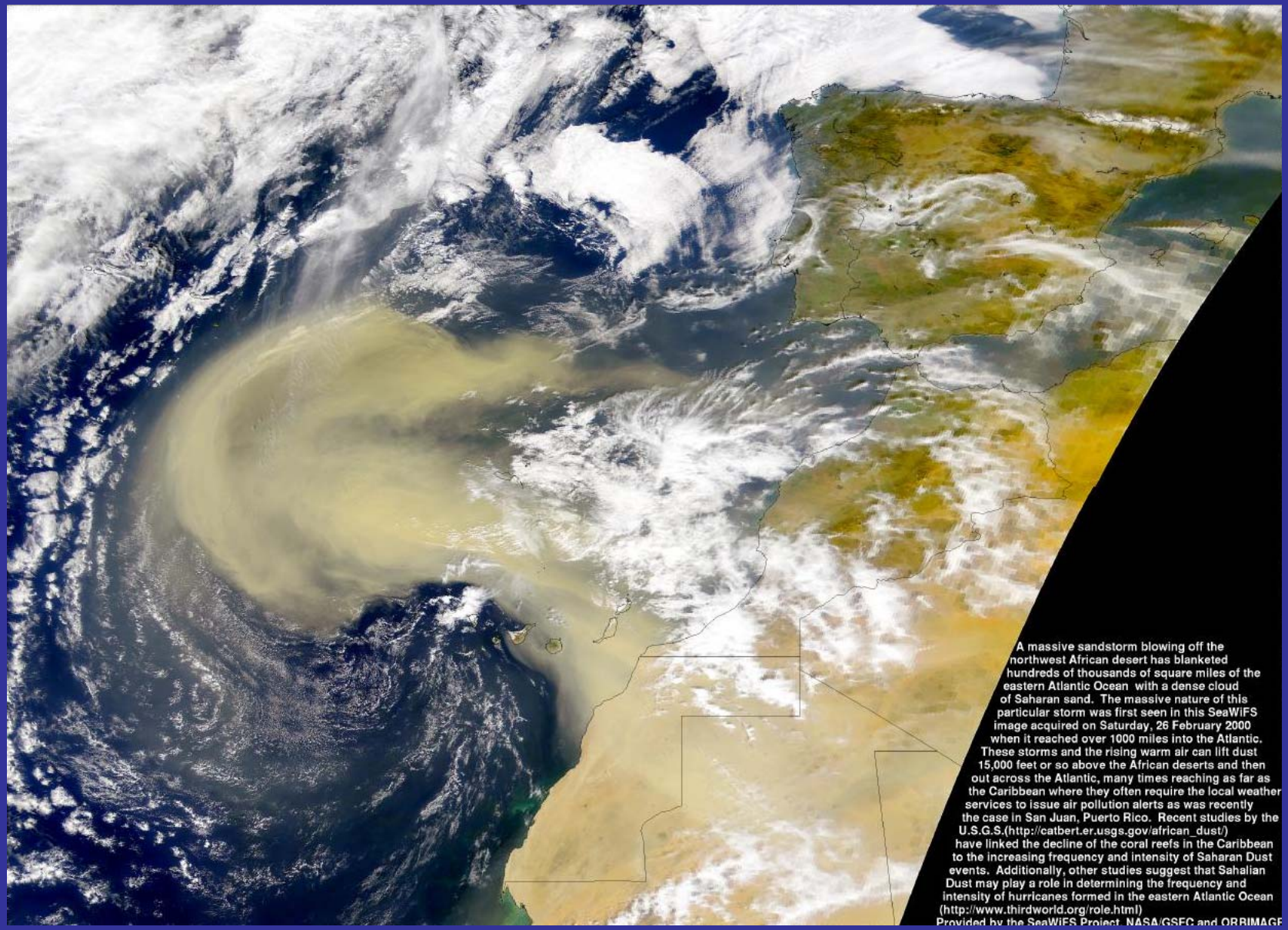
Red: Ground-based measurements (NOAA/CMDL)

Tropospheric ozone



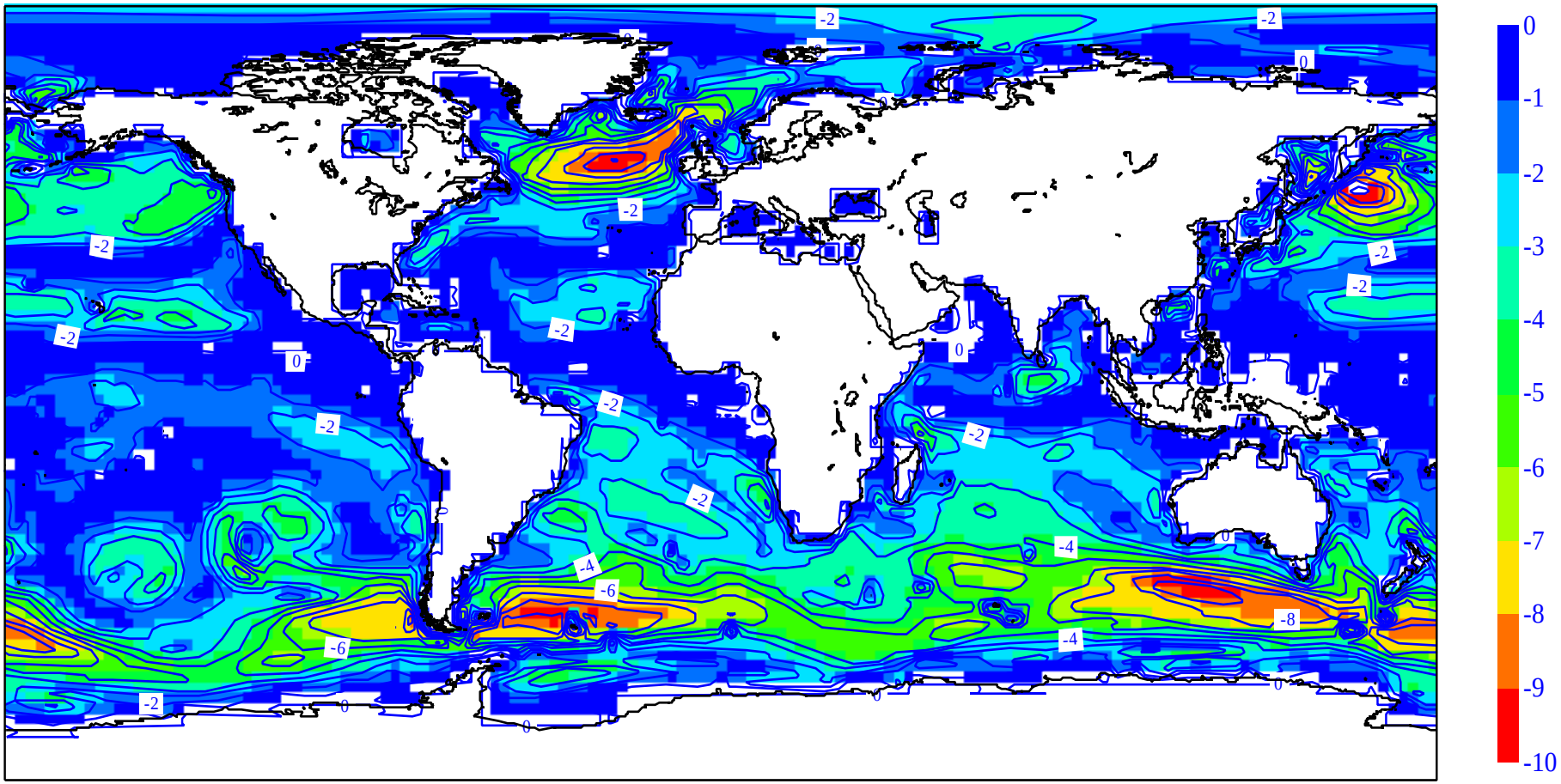
Ozone mixing ratio (nmol/mol) at 850hPa for 15UTC 3 August 2003, as simulated by MOZART-2 chemical transport model

Aerosol: satellite image of desert dust

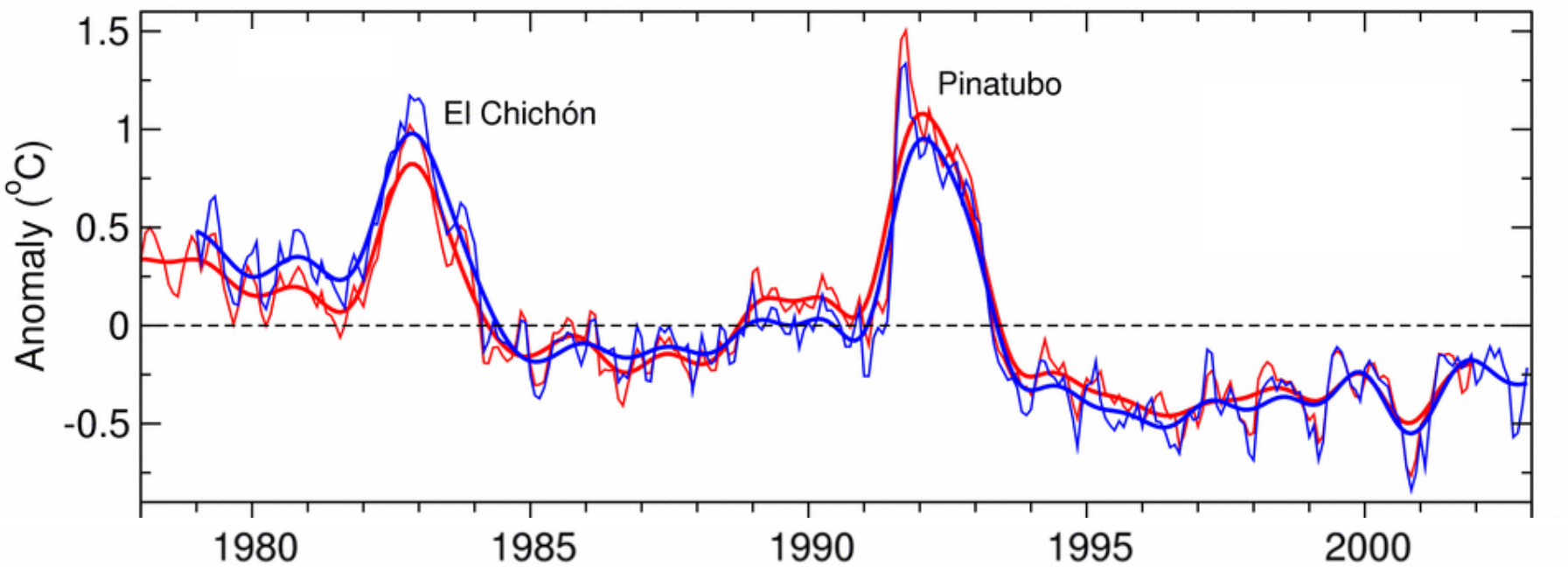


Aerosol: model source-term for salt

Sunday 15 October 2000 12UTC ECMWF Forecast t+120 VT: Friday 20 October 2000 12UTC Surface: **



Aerosol: Stratospheric warming due to sulphate aerosol from volcanic eruptions



MSU-4 data analyzed by Mears et al. (2003)

ERA-40 equivalent from Santer et al. (2004)

Implications for computing

- Good balance between HPC, data handling, servers, web services and networks is essential for reanalysis
- Reanalysis is a time critical HPC application, running at lower resolution and on lower number of processors than operations
- ERA-40 took 5-10% of Fujitsu resources for two years and produced ~70 Terabytes of data
- GEMS will start at reanalysis resolution; chemistry calculations are computationally demanding
- Elements of GEMS will find their way into high-resolution operations – demand for HPC will increase

In conclusion

- The last user job to run on ECMWF's Cray C90 was the final step of ECMWF's first reanalysis, ERA-15
- The last user job to run on ECMWF's Fujitsu VPP systems was the final step of ERA-40
- ECMWF plans to carry out a new reanalysis covering the period 1989-2008