12.812 General circulation of the atmosphere and climate change

Section 1: Data, averaging, and equations

1. Observational data
2. Space-time averaging and decomposition
3. Dynamical equations

Observational data needed for studies of the General Circulation

- Overall global coverage (both over land and ocean)
- Observations at least through the depth of the troposphere (and ideally including middle atmosphere)
- Well resolved in time and space to calculate eddy quantities accurately (~4 times daily, ~100km)

Observational data for studies of the General Circulation

Examples of data sources:

- Rawinsonde (upper-air temperature, wind speed/direction, humidity)

- Surface reports over land and ocean

- Remote sensing: satellite retrievals of temperature, humidity, column water vapor, feature tracking for winds

Observational data for studies of the General Circulation

- For calculation of statistics need to make consistent gridded data (analysis of the observations)

- Data sparseness in space and time is a major issue

Observational data for studies of the General Circulation

- Atmospheric figures in textbook by Peixoto and Oort based on spatial interpolation and 10 years of data (1963-1973)

- Modern method is to combine the data with an atmospheric general circulation model using data assimilation (includes analysis and initialization)

- Goal is minimization of discrepancy between observations and model variables (e.g., 3D or 4D var)

Reanalysis

- Model is held fixed over long time period but observational inputs vary

- Reanalysis was pioneered by Eugenia Kalnay (first woman to get a PhD in meteorology at MIT) and are now very popular

The **NCEP**/NCAR 40-year **reanalysis** project
E Kalnay, M Kanamitsu, R Kistler… - Bulletin of the …, 1996 - journals.ametsoc.org
The **NCEP** and NCAR are cooperating in a project (denoted "**reanalysis**") to produce a 40-year record of global analyses of atmospheric fields in support of the needs of the research and climate monitoring communities. This effort involves the recovery of land surface, ship …
Cited by 24845 Related articles All 24 versions Web of Science: 18405 Import into BibTeX

- Modern reanalyses: NCEP2, CSFR; ERA40, ERA interim, ERA5; MERRA, MERRA2

Timeline of observations assimilated in ERA40

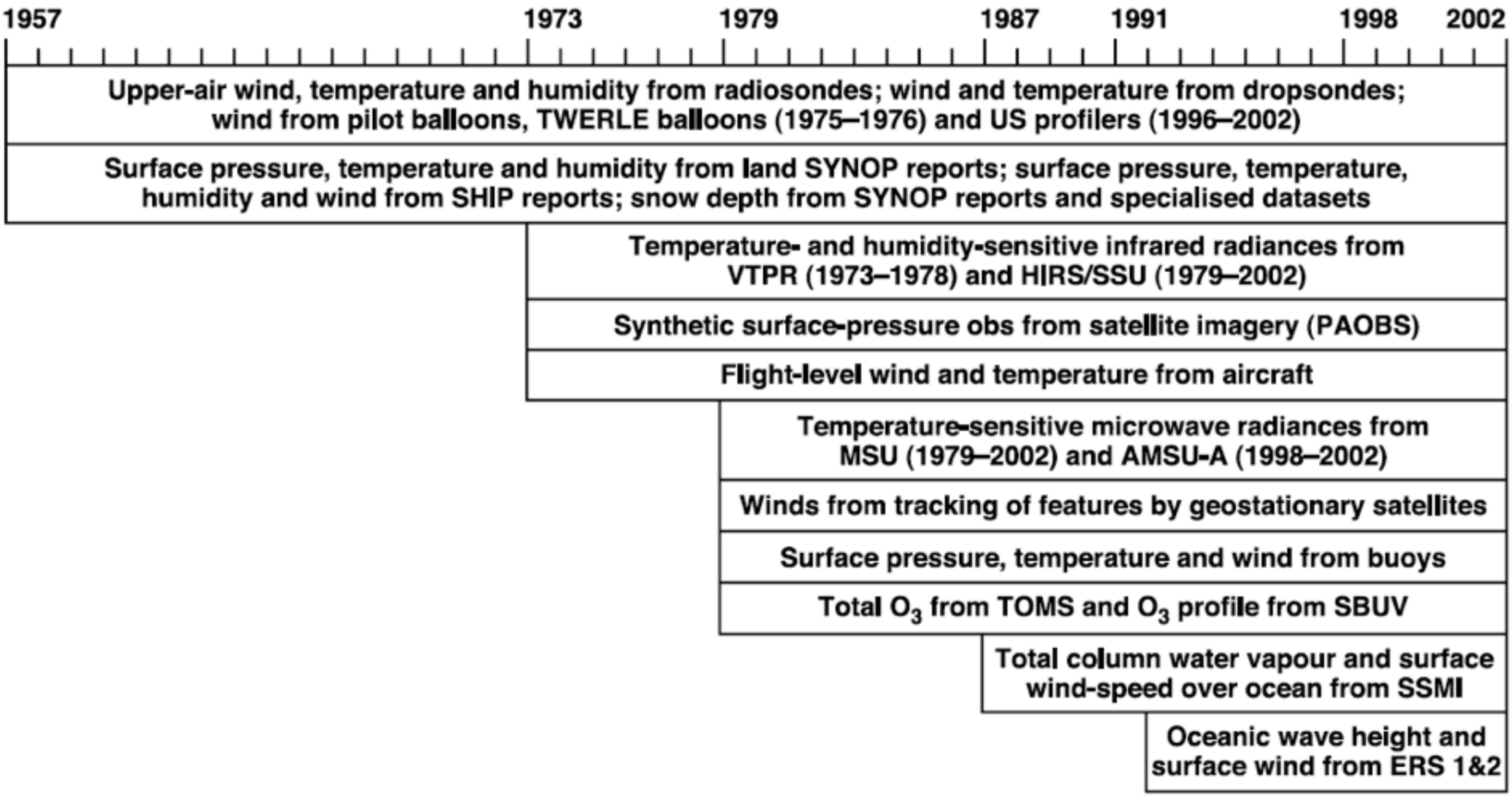


Figure 1. Chronology of types of observations assimilated in ERA-40 from 1957 to 2002. (See appendix A for acronyms.)

Uppala et al, QJRM 2005

Number of observations by type assimilated in ERA40

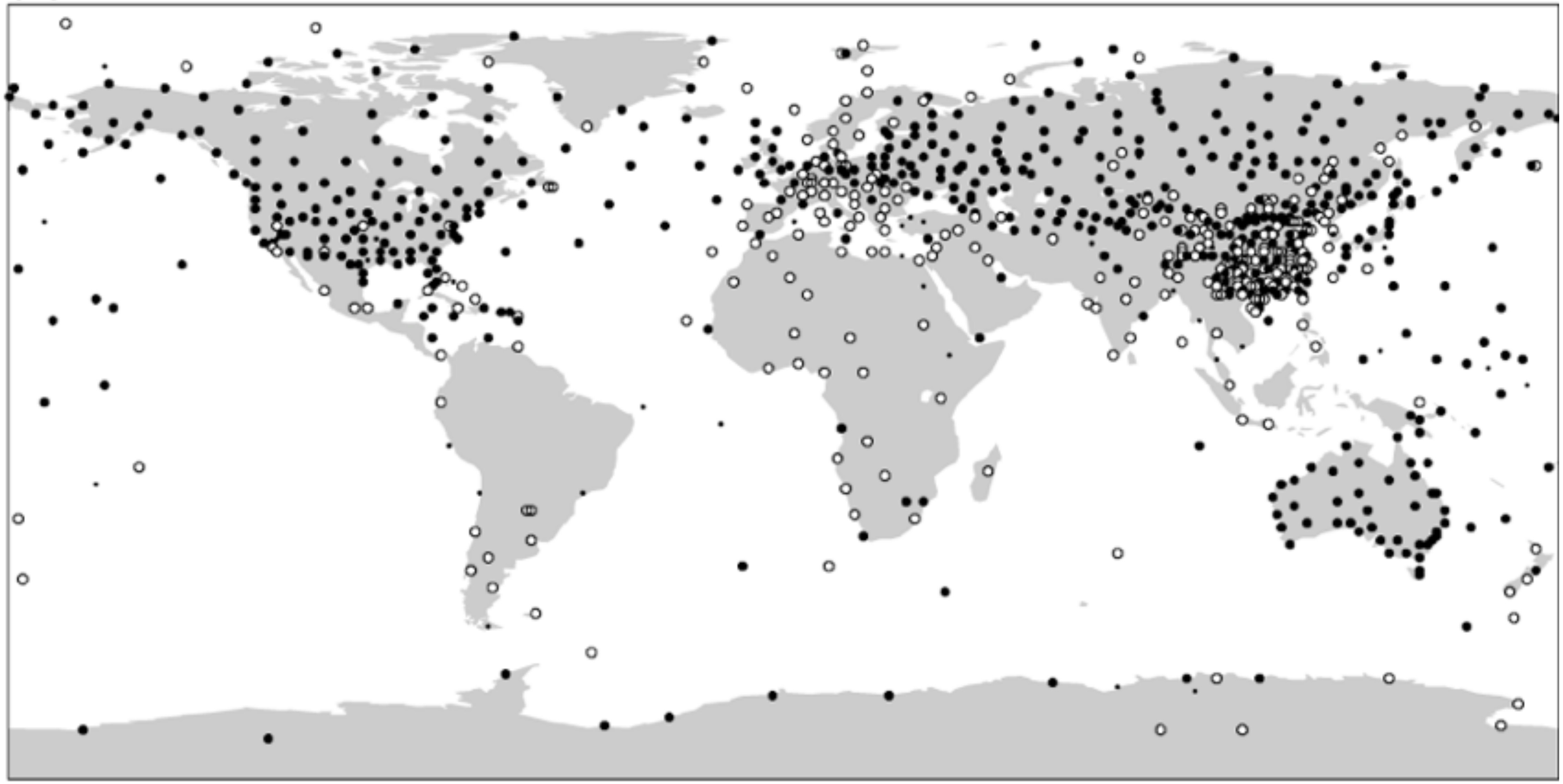
TABLE 1. AVERAGE DAILY COUNTS OF VARIOUS TYPES OF OBSERVATION SUPPLIED TO THE ERA-40 DATA ASSIMILATION, FOR FIVE SELECTED PERIODS

Observation type	1958–66	1967–72	1973–78	1979–90	1991–2001
SYNOP/SHIP	15 313	26 615	28 187	33 902	37 049
Radiosondes	1 821	2 605	3 341	2 274	1 456
Pilot balloons	679	164	1 721	606	676
Aircraft	58	79	1 544	4 085	26 341
Buoys	0	1	69	1 462	3 991
Satellite radiances	0	6	35 069	131 209	181 214
Satellite winds	0	0	61	6 598	45 671
Scatterometer	0	0	0	0	7 575
PAOBs	0	14	1 031	297	277

Uppala et al, QJRM 2005

Availability of radiosonde reports

(a) 1958



Solid circle: at least 3 reports per 2 days

Uppala et al, QJRM 2005

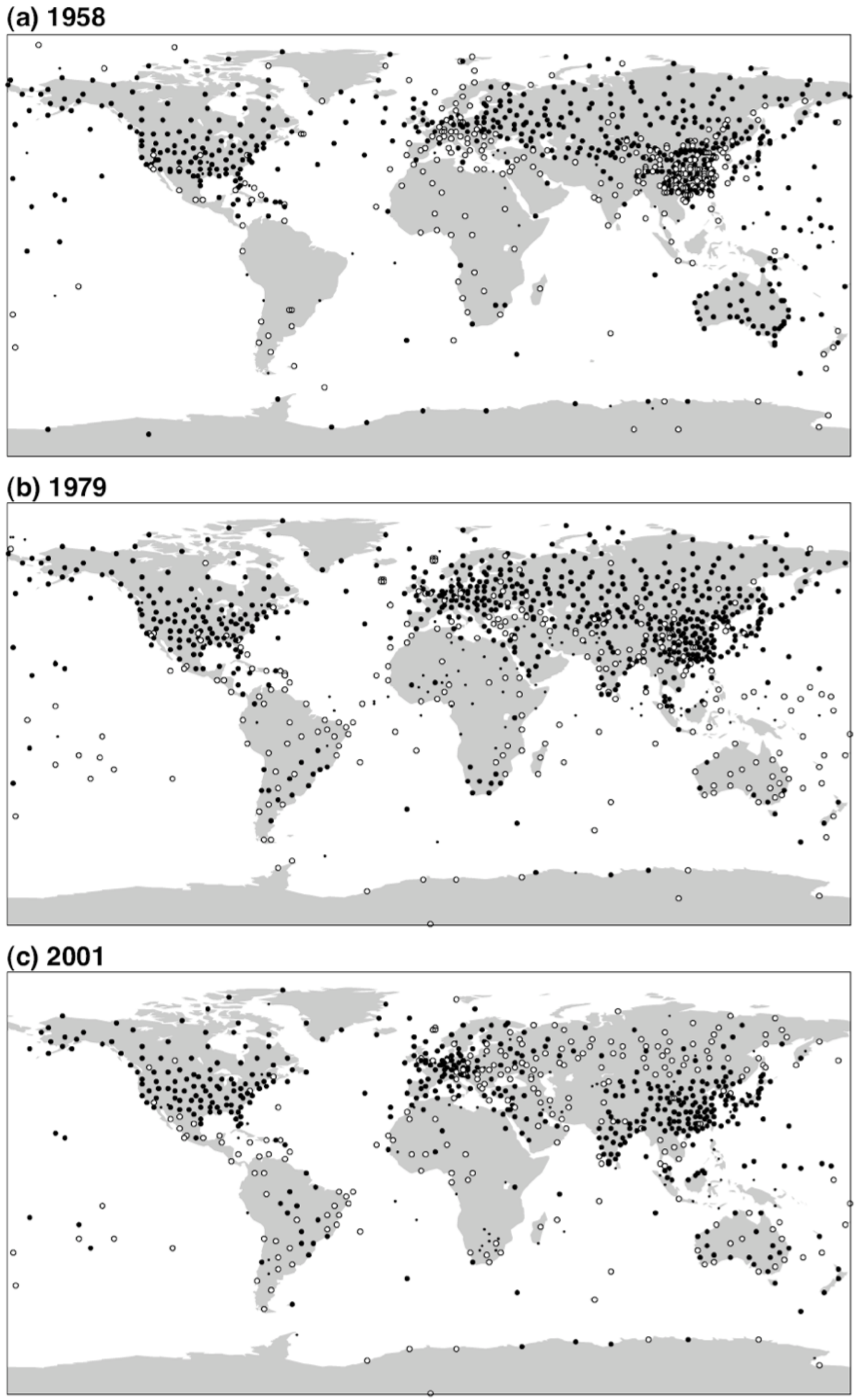
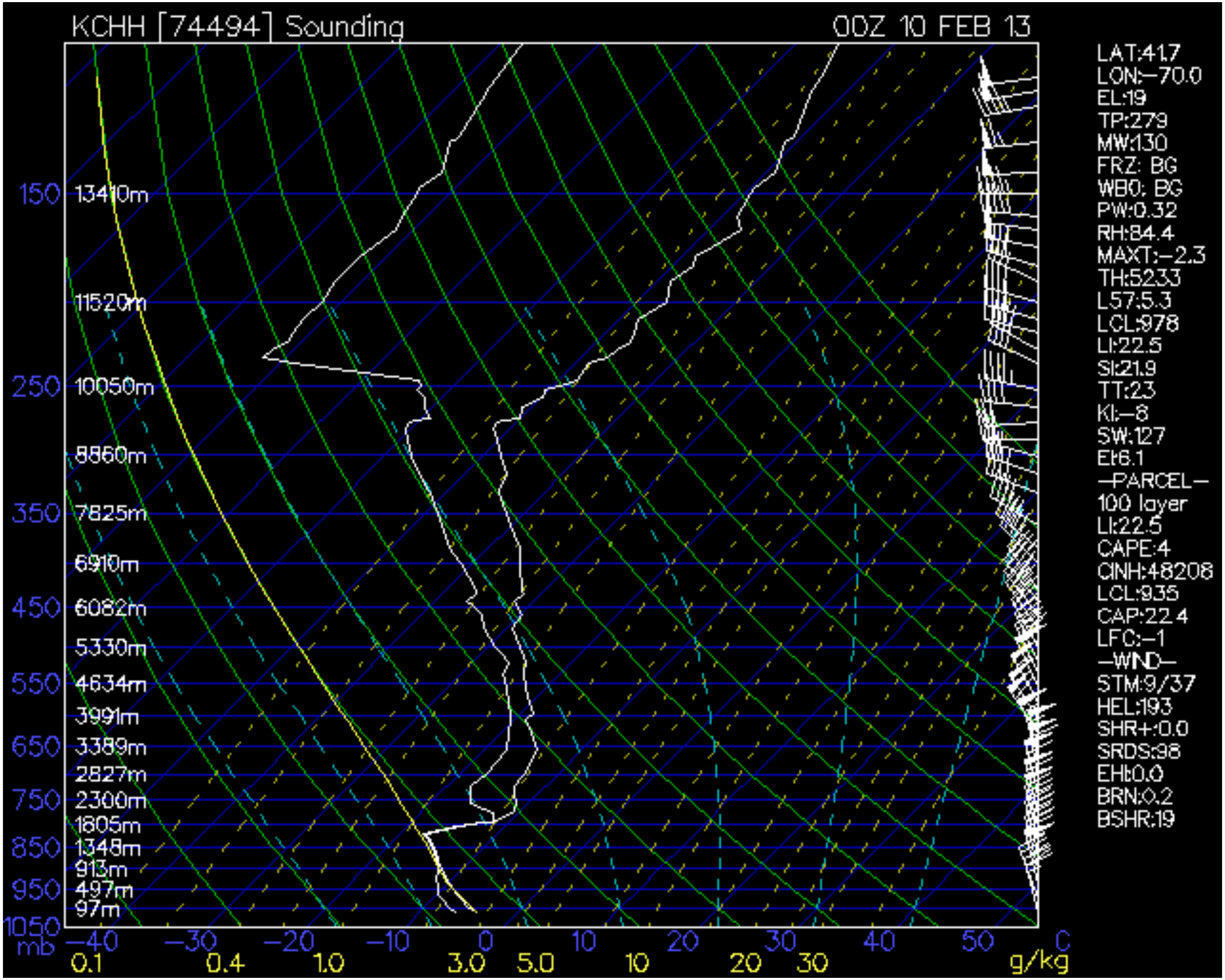


Figure 2. Frequency of radiosonde reports for: (a) 1958, (b) 1979 and (c) 2001. Solid circles denote stations from which at least three reports are available every 2 days on average, open circles denote other stations reporting at least once every 2 days, and small dots represent stations reporting at least once per week.

Uppala et al, QJRM 2005



Chatham MA (CHH-74494)

“20th century” reanalyses

- Use only surface data which has the advantage that it goes back further in time and is more homogeneous in time (20CR, ERA-20C)

- 20th century reanalysis project (20CR, Compo, 2010):
  - only assimilates SST, sea ice, and surface pressure
  - V3 is from 1836-2015! (3DVar would be hopeless because of lack of upper air observations)

Comparison of two reanalysis products

Table 1
Some aspects of the NDRa2 and ERA-40 input data

Dataset	NDRa2	ERA-40
Primary reference	Kanamitsu et al. (2002)	Uppala et al. (2005)
Input data		
Satellite data	NESDIS TOVS temperature retrievals, cloud track winds (no moisture data used)	Direct assimilation of VTPR, TOVS (HIRS, MSU, SSU) and AMSU-A Level-1c radiances, atmospheric motion vectors, scatterometer winds, SSM/I radiances as 1D-Var retrievals of TCWV and surface wind speed TOMS and SBUV data in ozone analysis, Altimeter wave height data (see Hernandez et al., 2004)
Upper air data	Radiosondes, dropsondes, pibals, aircraft data, wind profilers	Radiosondes, dropsondes, pibals, aircraft data, wind profilers
Surface data (snow cover)	Stations, ships, buoys, PAOBs (NSIDC-based, USAF snow cover after fall 1998, depth is dynamic)	Stations, ships, buoys, PAOBs (SYNOP snow depth, most after 1976)
SST and sea ice	AMIP-II (should be same as ERA-40 except for time interpolation, Kanamitsu, personal communication, 2007), Reynolds SST after 1999	Reynolds et al. (2002), Rayner et al. (2003) and other NCEP products
Period	1979-Present	September 1957–August 2002 (45 years)

Note: Not all data were available during the full length of the assimilated period. See the original references for details. Acronyms and abbreviations are defined in Appendix A.

Grotjahn, 2008

Table 2
Some aspects of the NDRa2 and ERA-40 assimilation systems

Dataset	NDRa2	ERA-40
Primary reference	Kanamitsu et al. (2002)	Uppala et al. (2005)
Period	1979-Present	September 1957–August 2002 (45 years)
Assimilation model		
Model based on	MRF (ca. 1995, with modifications) full radiation calculation hourly	ECMWF forecast model CY23r4 (operational in June 2001)
Assimilation scheme	3DVAR (Parrish and Derber, 1992)	3DVAR-FGAT, OI for surface parameters and ocean wave height
Horizontal type, resolution (grid type, in latitude × longitude)	Spectral, T62 (Gaussian, 94 × 192 for dynamics and physics)	Spectral, T159 (linear reduced Gaussian grid 160 by up to 320, declining for latitudes >27°; Hortal and Simmons, 1991)
Vertical coordinate type, number of levels	Sigma, 28	Hybrid sigma (Simmons and Burridge, 1981), 60
Horizontal grid, levels used here	2.5° latitude by 2.5° longitude, 17 levels	2.5° latitude by 2.5° longitude, 17 levels
Parameterizations		
Orography	Smoothed mean orography to remove Gibbs oscillations	Smoothed mean orography
Land surface	Pan and Mahrt (1987) and Mahrt and Pan (1984). Soil moisture correction based on model minus observed precipitation	Viterbo and Beljaars (1995) and van den Hurk et al. (2000)
PBL	Hong and Pan (1996)	Beljaars and Viterbo (1999) and Viterbo et al. (1999)
Radiation	Chou (1992), Chou and Lee (1996) (shortwave) and Fels and Schwarztkopf (1975) (longwave)	Morcrette (2002a) (shortwave), Morcrette (2002b) (longwave), see also Gregory et al. (2000)
Time varying radiatively active: gases/aerosols (i.e. volcanic eruptions)	No (CO_2 constant)/no	Yes (CO_2, CH_4, N_2O, CFC-11, CFC-12, based on Houghton et al., 1996)/no
Convection	Simplified Arakawa Schubert, Grell (1993)	Tiedtke (1989) type, see Gregory et al. (2000)

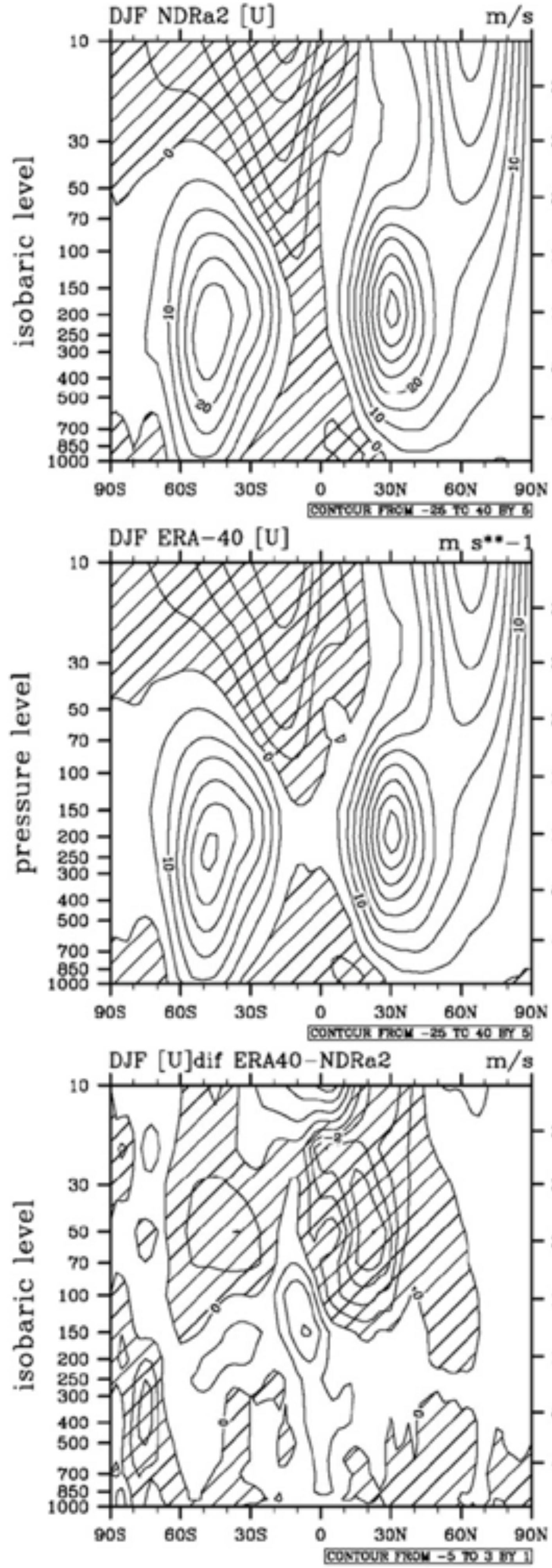
Acronyms and abbreviations are defined in Appendix A. *Data sources*: NDRa2: http://nomad3.ncep.noaa.gov/ncep_data/index.html; ERA-40: http://data.ecmwf.int/data/d/ERA-40_mnth/.

Grotjahn, 2008

NCEP2
(CI 5 m/s)

ERA40
(CI 5 m/s)

ERA40-NCEP2
(CI 1m/s)



Zonal wind in the zonal-and time-mean in DJF

Grotjahn, 2008

Use of reanalysis products for climate change

- Care is needed if using reanalysis for trend analysis (although model held fixed, very different observations used over time)

- Advisable to use only after 1979 and important to compare to observations where available

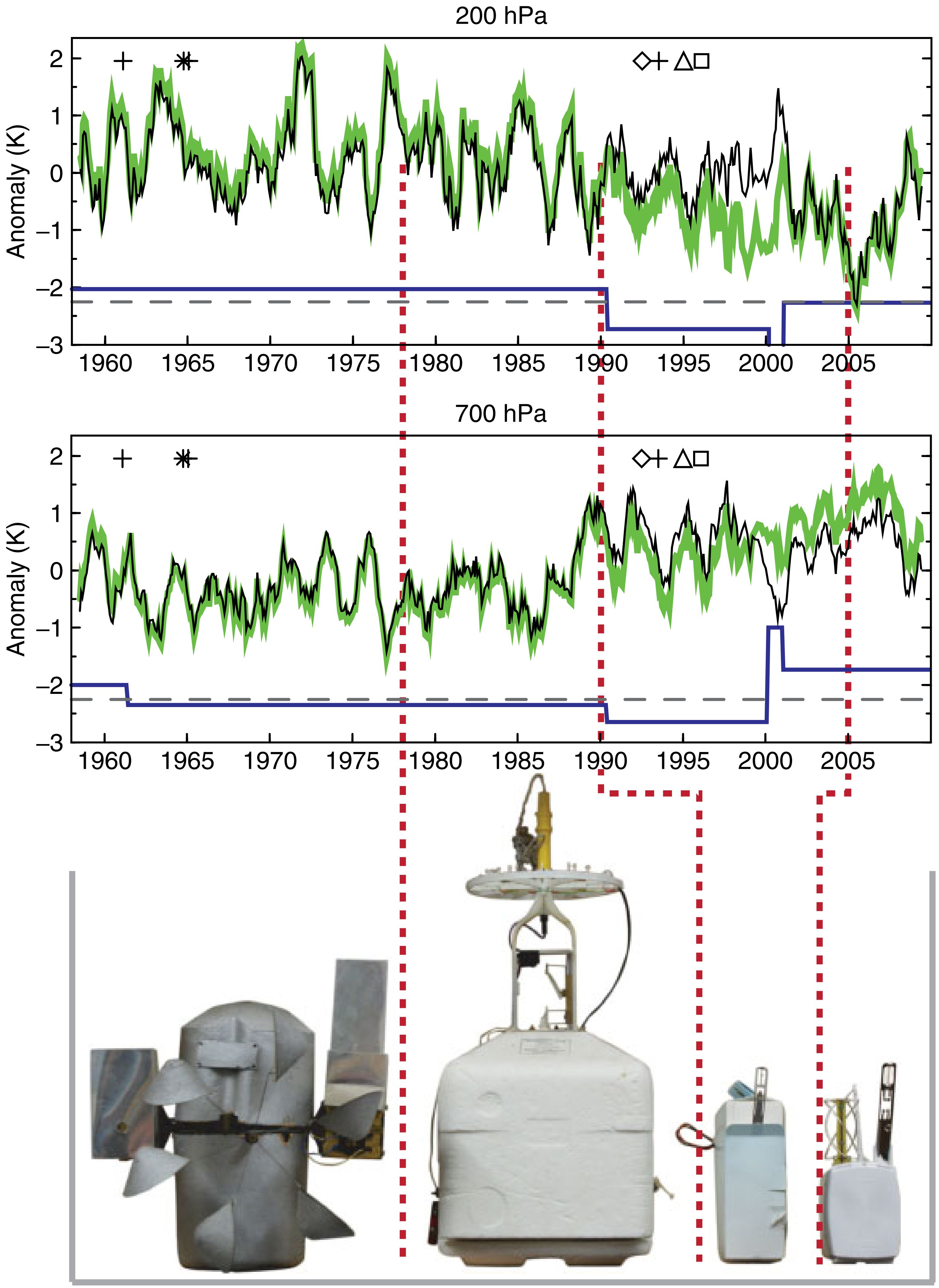
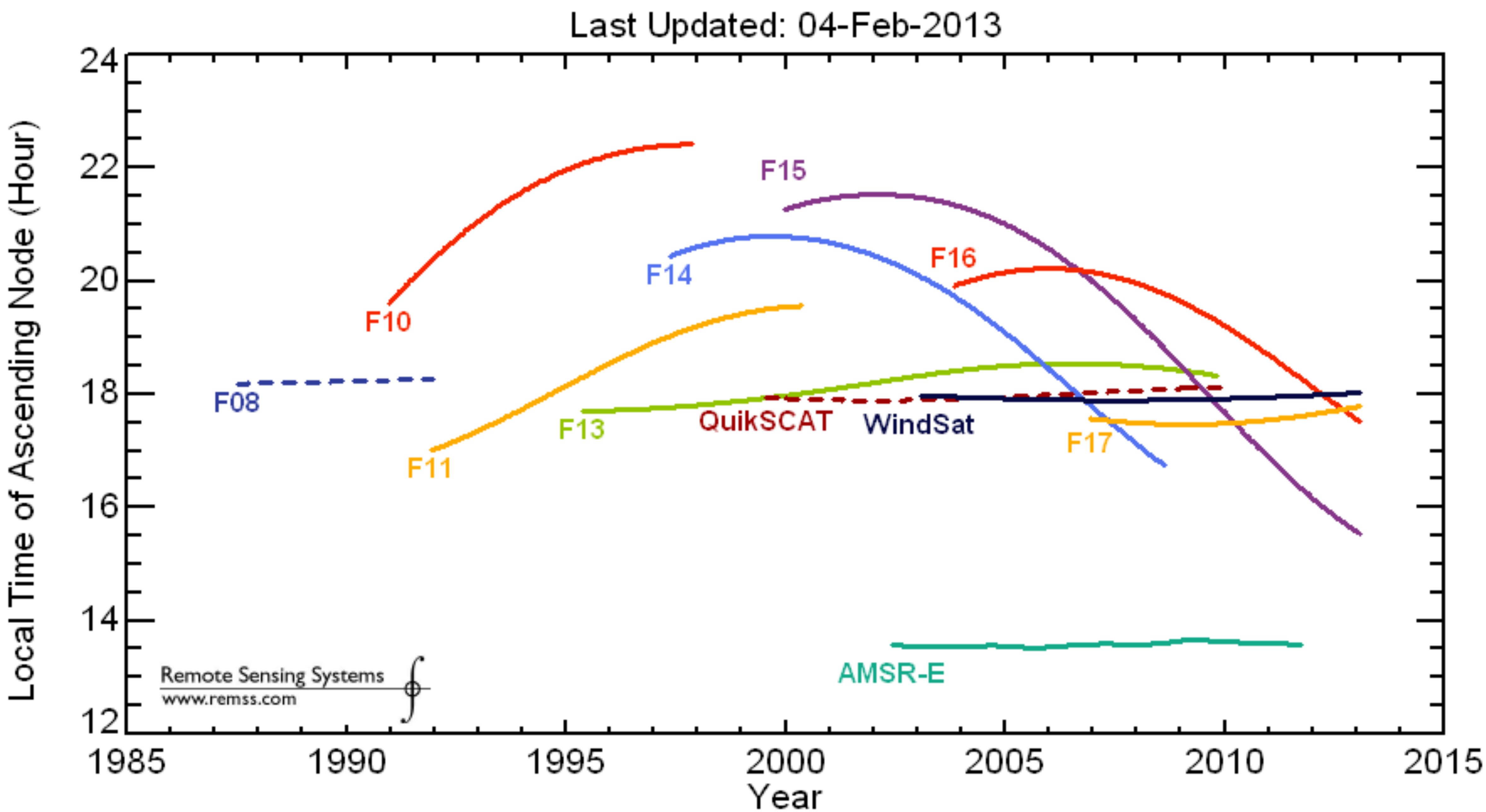


FIGURE 3 | Top 2 panels: monthly temperature anomalies (smoothed with a 13-point running average) during 1958–2009 from radiosonde observations at Camborne, Cornwall, UK, at 200 hPa (near-tropopause) and 700 hPa (lower-troposphere), including both raw (black) and adjusted (green) HadAT data.[7] The smoothed difference series between the two shows the adjustments (offset by 2.25 K). Bottom panel: the four radiosonde types used over this period (typical of UK-managed stations) are (left to right, with typical periods of operation): Phillips Mark IIb (1950s–1970s); Phillips MK3 (mid 1970s to early 1990s); Vaisala RS-80 (early 1990s to 2005–2006); and Vaisala RS-92 (since 2005–2006). Dates of radiosonde changes (red dotted lines) are one sort of 'metadata event',[5] others include: cross—radiation correction procedure change; star—data cut-off change; diamond—change of pressure sensor; triangle—change of wind equipment; square—change of relative humidity sensor. Photos courtesy of Kevin Linklater, UK Met Office and background digitally enhanced for clarity by Sara Veasey NOAA NCDC.

Thorne et al, WIRES, 2012

To obtain long time series, need to piece together data from multiple satellites (and orbits of satellites can change)



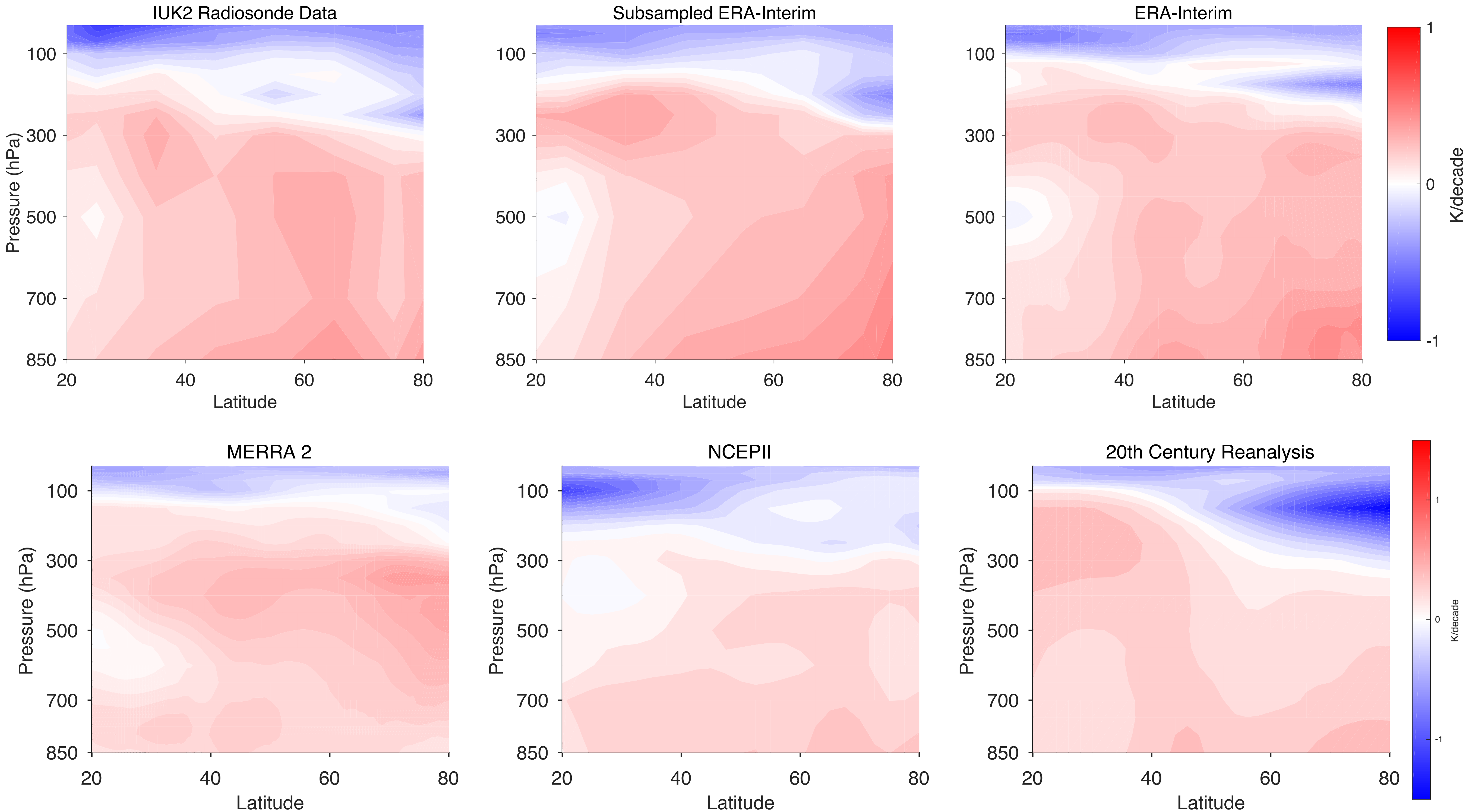
Ascending Local Equator Crossing Times: F10, F11, F13, F14, F15, F16, F17, AMSR-E, WindSat

Descending Local Equator Crossing Times: F08, QuikSCAT

RSS website

Comparison of temperature trends over 1979-2016 for JJA in the northern hemisphere

Figures courtesy Charles Gertler



Radiosonde trends and subsampled ERA–interim trends are median trends over radiosonde station locations in 10 degree latitude bands;
All others are zonal means