Homogenization of IR sounders

Mark McCarthy – ECMWF workshop, 22nd June 2006

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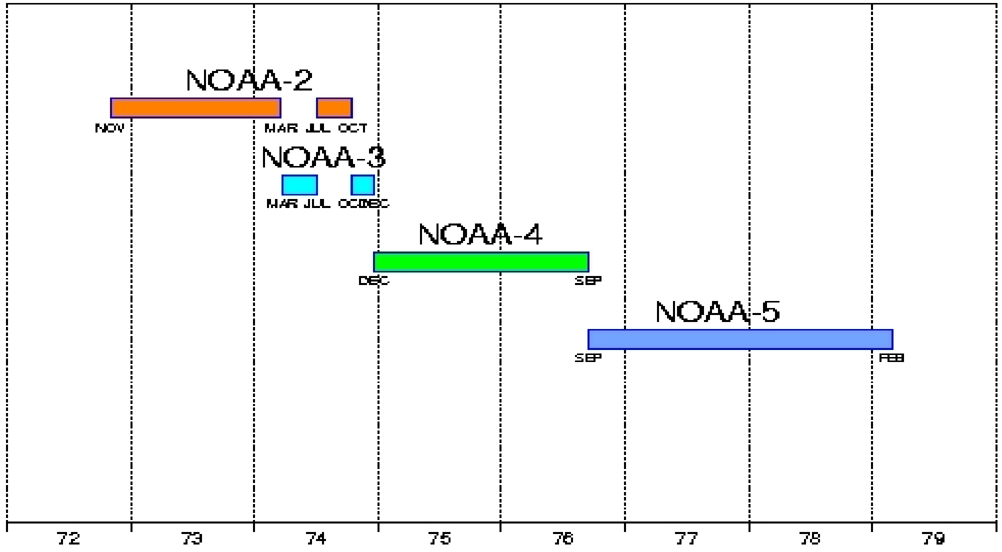
Plus reference work of: John Bates, John Christy, Darren Jackson, Chongyang Cao, Carl Mears, Roy Spencer, and others

Outline

1. Introduction and aims.
2. Existing datasets and their utility.
3. Clouds
4. Treating known biases.
5. Summary + discussion

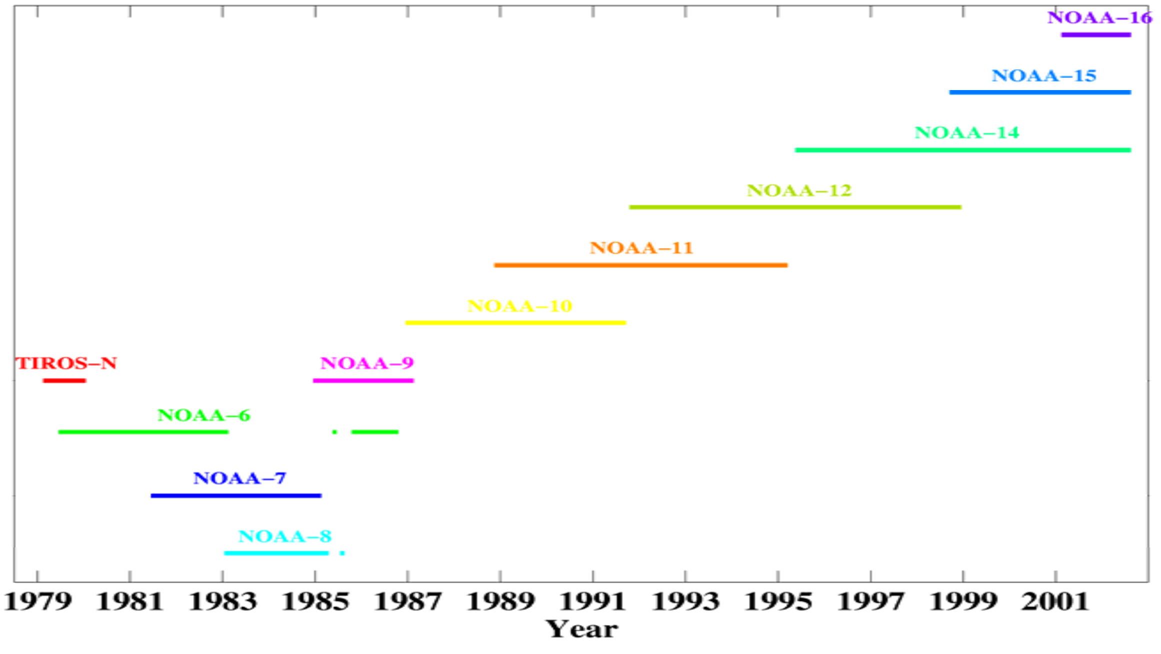
Introduction and aims

Global observations since 1972



VTPR

(A)TOVS



IR sounders instrument capabilities

	VTPR	HIRS/2 & 3	HIRS/4
Time frame	1972-1979 NOAA-2 to NOAA-5	1975- Nimbus-6 to NOAA-14 NOAA-15 to NOAA-17	2005- NOAA-18 (-19) METOP-1 and 2
Spectral coverage	8 longwave (12-18um) (15µ CO2, 12µ window, 18u H_2O)	12 longwave (6.5-15 µm) 7 shortwave (3.7-4.6 µm) 1 visible (0.69 µm)	
Swath	~1020 km (±30.3º)	~2230 km (±49.5º)	
FOV at nadir	56 km	20 km (1.4º max)	10 km (0.7º)
Number of FOV	23 2.7º step / 0.5 sec	56 1.8º step / 0.1 sec	
Scan time	12.5 sec	6.4 sec	
Radiometric calibration	BB (“patch”) and space. Takes 37.5 s normally once per orbit (could be every 7 min)	BB and space. Takes 12.8 s every 256 sec	

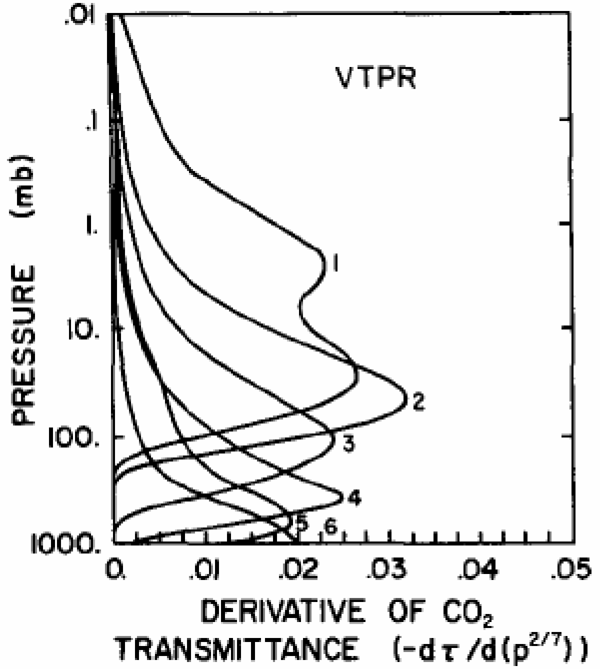
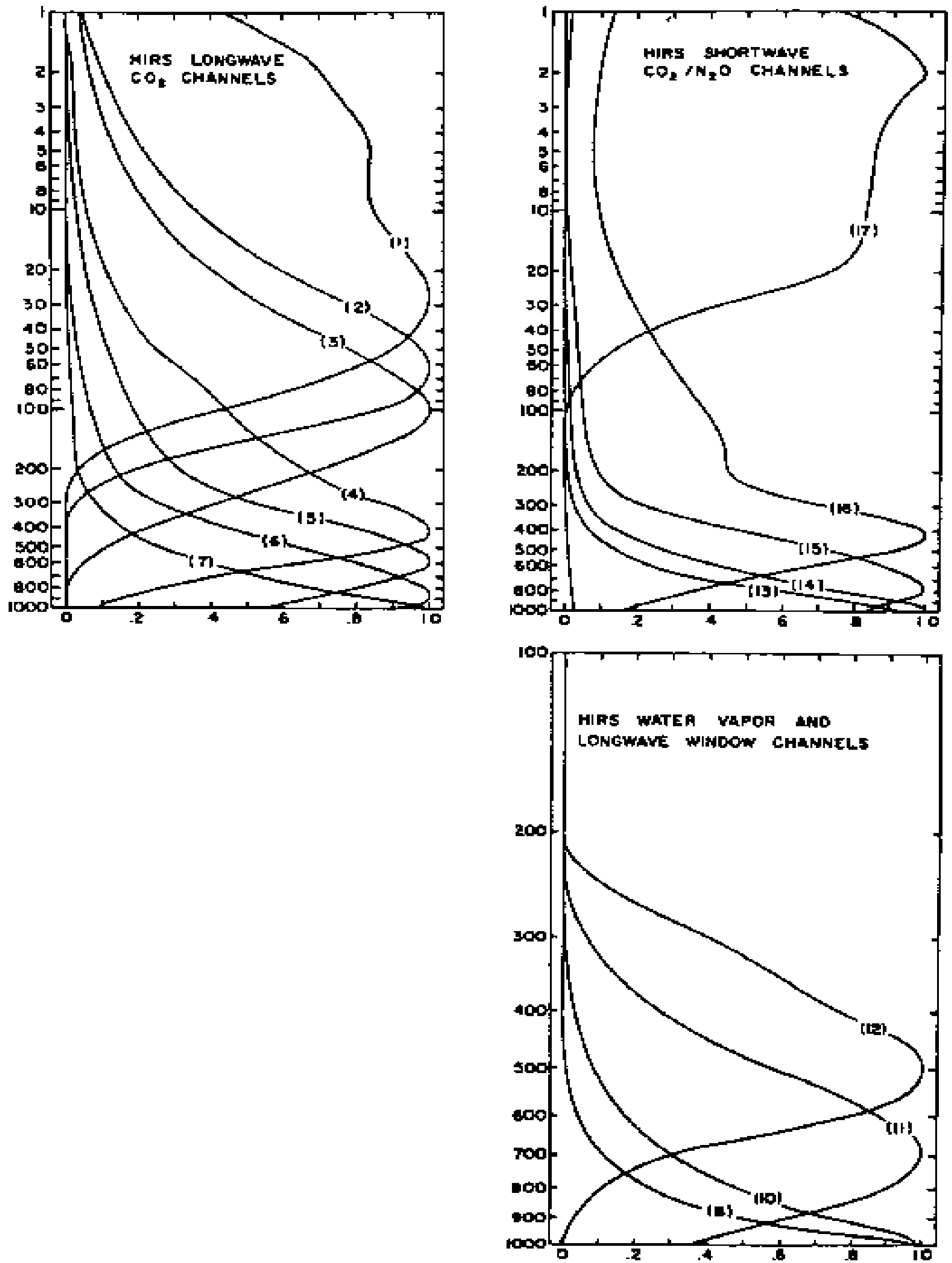


FIG. 1. VTPR CO_2 channel weighting functions for U. S. Standard Atmosphere.



- Given an opportunity to reprocess IR sounders:
  - Is it worth doing?
  - What lessons have we learnt from previous efforts?
  - How should it be done for maximum benefit?

Aims

- To provide a record of homogenised clear-sky infra-red radiances from satellite observations, 1972-2010+
  - Quantify and reduce uncertainties in temperature and humidity changes aloft.
  - Validate and interpret biases in climate models, through direct comparison of simulated and observed radiances.
  - Evaluate important climate feedbacks on annual to decadal timescales.
  - Input to next generation reanalyses.

Resources and timeframe

- Development of a homogenised radiance dataset from HIRS (+VTPR), 2007-2009.

- Essential to have active collaboration within the UK and internationally.

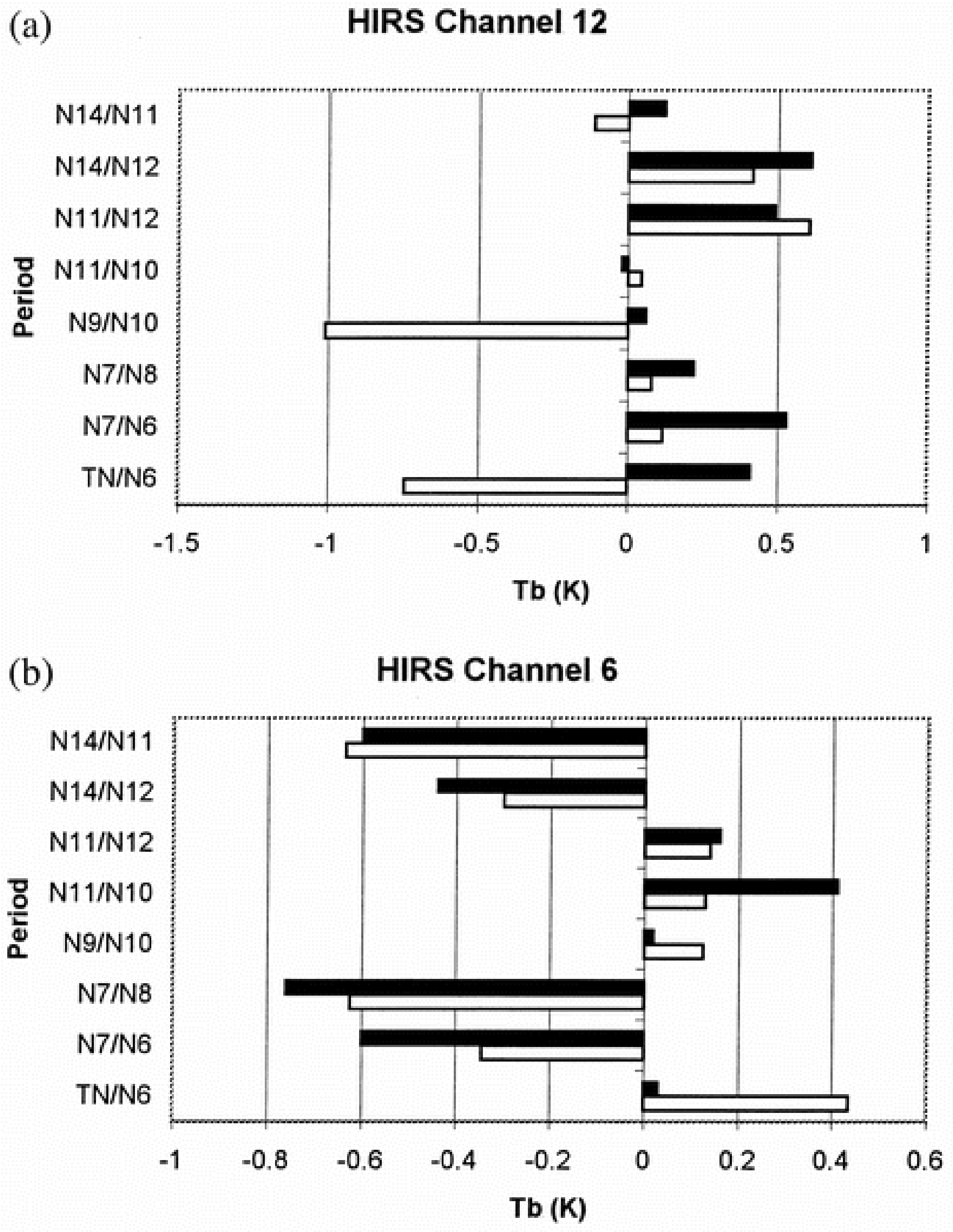
Existing data sets and their utility

Existing datasets and their utility

- Jackson and Bates (2001) - Pathfinder
  - 1b radiances calibrated and converted to Tb using ITPP and AAPP packages. Uses HIRS/2 only (TIROS-N to NOAA-14) channels 1-12.
  - 11.1µm channel used for cloud detection.
  - Pentad and monthly means on a 2.5x2.5 grid.
  - Empirical adjustment process for inter-satellite calibration, except NOAA-7 to NOAA-9.
  - Inter-satellite correction de-trends.
  - Pathfinder version 2 does not include inter-satellite adjustments.

Satellite-to-satellite systematic biases for HIRS (a) channels 12 and (b) 6
computed from forward physical principles (solid bar) and from empirical dynamic function analysis (open bar).

Figure From Bates et al. (2001) JGR, 106, D23, p.3272



Existing datasets and their utility

- Jackson and Bates (2001)
  - Inter-annual variability good. For example, Bates et al. (2001) *JGR*, Allan et al. (2003) *QJRMS*, Soden et al. (2005) *Science*.
  - Trends are questionable! Bates et al. (2001) *GRL*, McCarthy and Toumi (2004) *J. Clim,* Jackson (personal comm.)
  - Darren Jackson is currently working on an orbit drift correction for the pathfinder data set.

Existing datasets and their utility

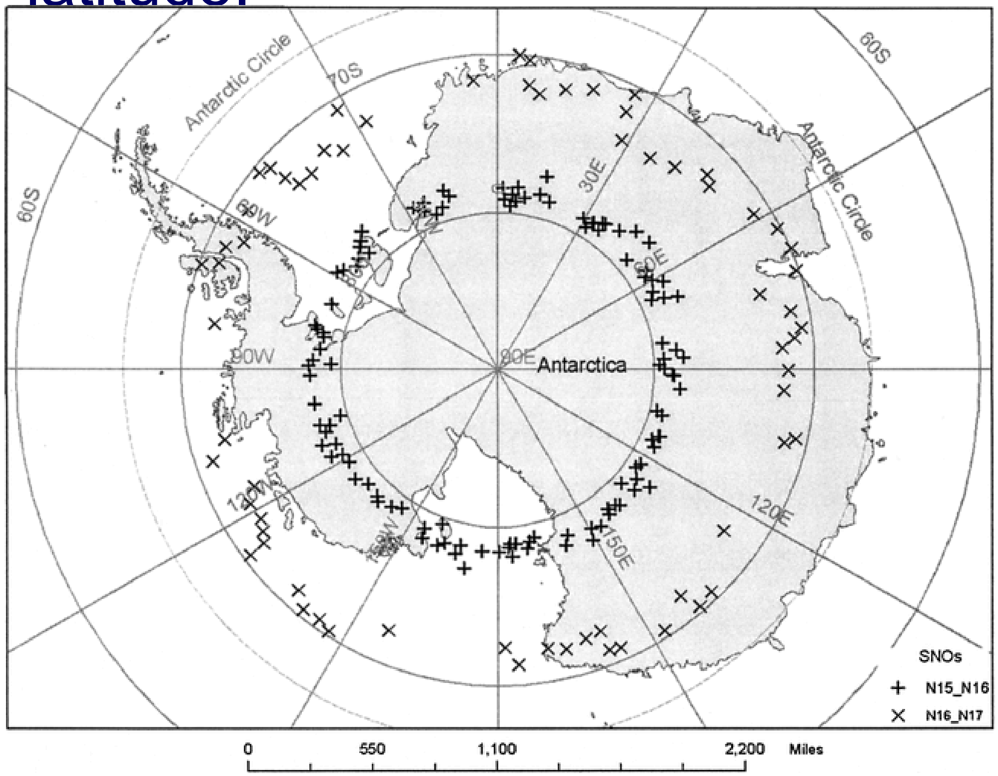
- Lei Shi, John Bates (NCDC) – in progress
  - Neural network retrieval of T and q on 18 pressure levels from HIRS pathfinder.
  - Training dataset from ERA-40.
  - Include CO_2 correction.
  - Plan to revisit inter-satellite calibrations.

Existing datasets and their utility

- Soden et al. (2005), *Science* and Huang et al. (2005), *GRL* – Channels 5, 11 and 12 (14, 7.3, and 6.7μm)
  - Minimised differences of global, monthly mean Tb between satellites.
  - N7 to N9 applied a curve-fit to the Tb anomalies over this period.

Existing datasets and their utility

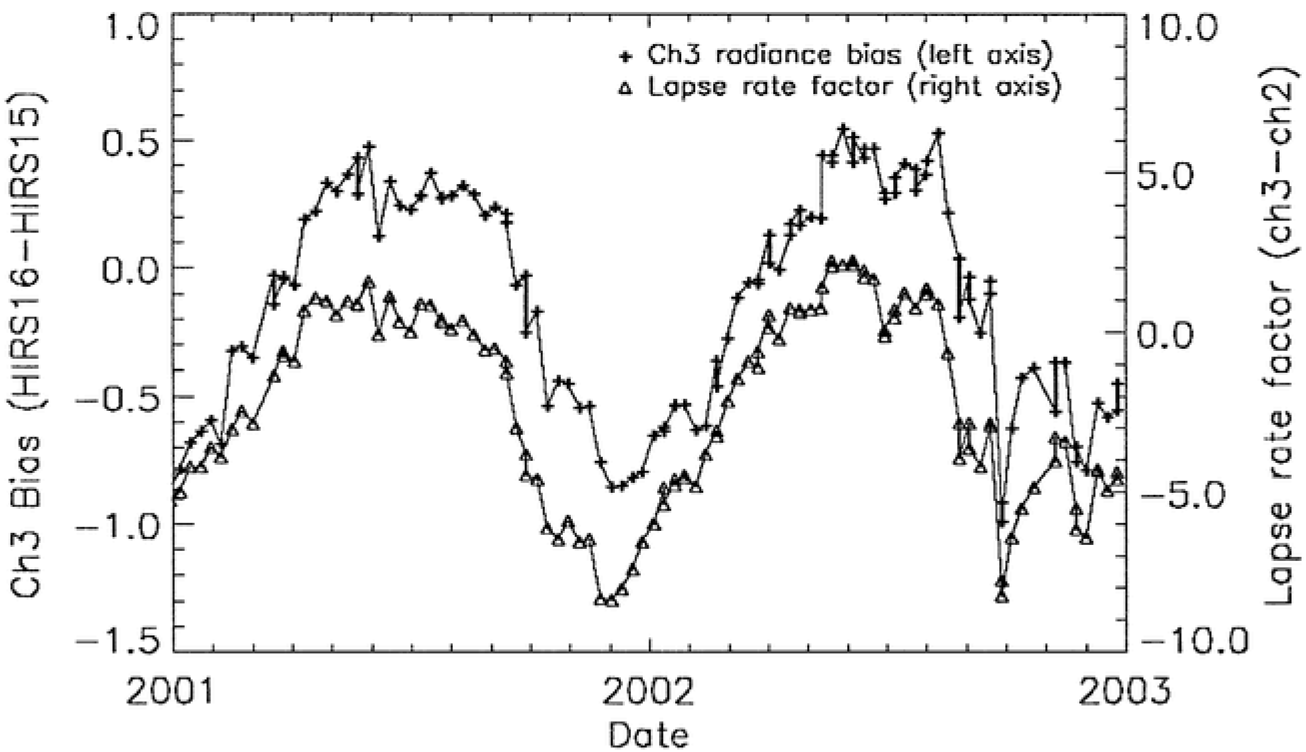
- Cao et al. (2005) *J. Atmos. Ocean. Tech*.
  - Inter-satellite radiance biases from Simultaneous Nadir Observations (SNO).
  - Nadir points cross within 30s.
  - Every 8-9 days at 70^{o}-80^{o} latitude.



SNO locations between NOAA-15 and NOAA-16 (+) and NOAA-16 and NOAA-17 (x), 2000-2003.

Existing datasets and their utility

- Cao et al. (2005)
  - Strong correlation of bias to lapse rate factor (stratospheric temperature channels used in this example).



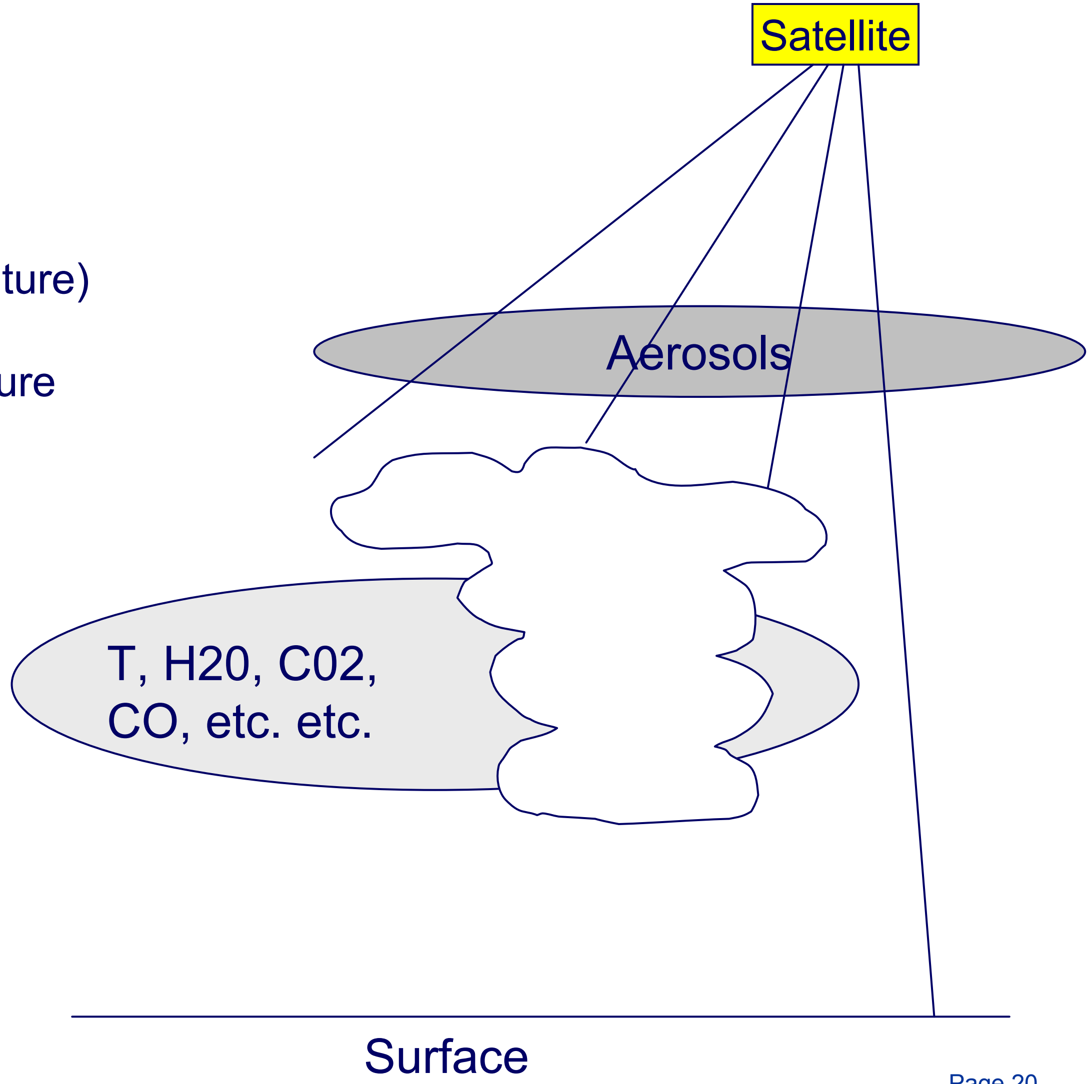
Correlation between the seasonal radiance bias for channel 3 and the lapse rate factor

Existing datasets and their utility

- Cao et al. (2005)
  - Bias not always explained by known changes in spectral response functions.
  - Pre and post launch spectral calibration may be insufficient to predict small biases.
  - SNO has been conducted on all HIRS data N6 to N17.
  - Insufficient data to assess N8 to N9.
  - Biases are estimated from arctic/antarctic atmospheres only.

Clouds

- IR sounders sensitive to
  - Cloud properties (fraction, temperature)
  - Relative Humidity
  - Atmospheric and surface temperature
  - Greenhouse Gases
  - Aerosols
- Measurement sensitive to
  - Spectral response
  - Radiometric response (gain)
  - Pre and post-launch calibration
  - Fov response (+spatial sampling)
  - Viewing geometry



- Cloud-cleared or clear-sky only products are biased toward anomalous atmospheric conditions. ~95% fov are cloudy.

- Valuable climate information on water vapour and clouds could be lost in a cloud-free product.

- Interpretation of all-sky radiances through appropriate use of models and reanalyses rather than cloud-clearing and geophysical retrievals.

- However, the changing footprint size over time is a challenge given the inhomogeneous distribution of water and cloud.

- Cannot escape the need for some form of cloud detection.
  - Compare window channel (11.1µm) to surface temperatures.
  - Use coincident IR imagers.
  - Use NWP background
- Use recent period to investigate differences in cloud-detection approaches.

Treatment of Known Biases

Changes in channel/filter response

- Changes in the SRFs are the most likely cause of inter-satellite bias.

1. Changes in SRF from instrument to instrument.
2. Inadequate pre-launch measurement of SRF.
3. Shift in SRF may occur post-launch.

4. Channels 10 and 12 (water vapour), 16 and 17 (SW C02) were changed from HIRS/2 (N14) to HIRS/3 (N15)
5. HIRS/2 to HIRS/3 biases are large for some channels that have not changed (Jackson 2003).

Changes in channel/filter response

- Some existing methods for calibration:

1. Forward model the bias from the given HIRS SRF.
   - Fails when SRF poorly characterised.
2. Compare radiances from GOES and Meteosat.
   - Must account for sampling errors and different SRF.
3. Calibrate to AIRS/IASI radiances
   - Lack of historical observations and same problems as 1.
4. SNO
   - Mostly arctic atmospheres used – N8-N9 difficult
5. Correct bias in aggregated values.
   - Mask non-linear effects. Too crude for some applications?

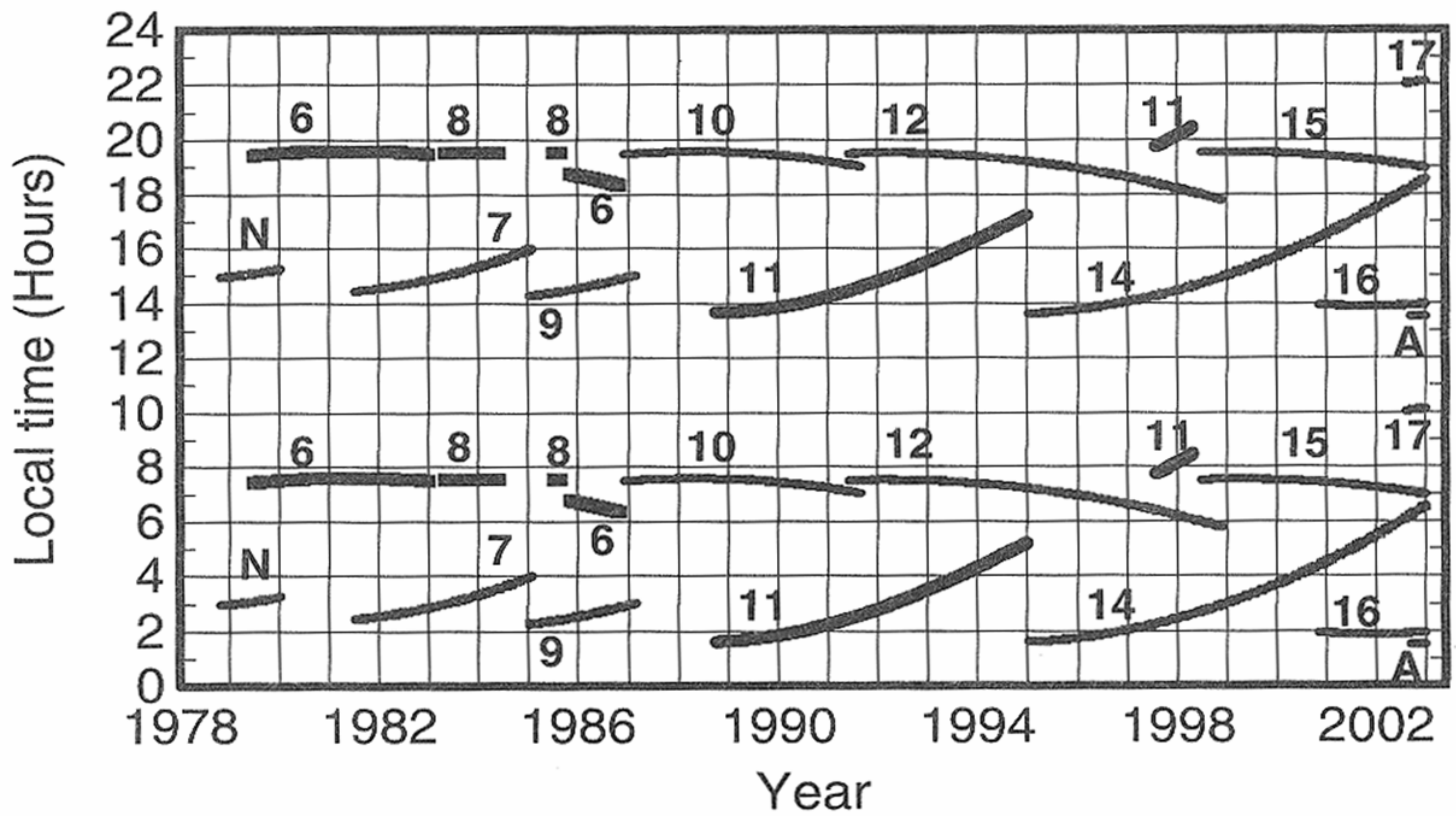
Changes in channel/filter response

- Challenges
  - Poorly defined SRFs. Can this be improved?
  - HIRS/2 to HIRS/3 to HIRS/4 transition and channel reassignments.
  - N8 to N9 transition. Can we use reanalyses as a ‘bridge’?

Orbit drift and decay

- Challenge: Patching together a series built from several different satellites with different orbital characteristics.
- Corrections:
  - Orbit decay -- satellite gets closer to Earth
  - Diurnal drift -- afternoon satellites drift so they come overhead later in the day (aliasing in the diurnal cycle)

Change in LECT – orbit drift



As 2006: N-15 drifted back to 5:48 while N-16 drifted to 3:10.

Approaches to correction

- Be clear what is being estimated.
  - 24 hour mean radiance?
  - Radiance at (local) noon?
- Need estimate of diurnal cycle for each channel.
- Could get from climate/weather model(s) – Mears et al & Jackson & Soden. Do we trust model Diurnal cycle well enough to do this?
  - Could validate against MSG which has some sounding channels.
- Could use periods with several NOAA satellites flying to estimate corrections – statistical modelling. Spencer & Christy.
  - Would need to correct for different HIRS instruments.

Orbit decay

- Satellite height decays – due to atmospheric drag.
- Affects off-nadir views.
- Could correct using standard atmospheres (Christy & Spencer) or reanalysis. Either way simulate radiances and use them to correct.

Other issues

- Other issues to consider
  - Quality of in-orbit calibration
  - Stability of filter functions
  - Filter wheel motor can be unreliable (e.g. NOAA-15)
  - NOAA-18 long-wave channels noisy
  - Interference from SSU
  - In-orbit stability of SRF
  - Others?

Summary

Summary - I

- IR sounders have already proven themselves as a valuable resource for climate research both directly, and through reanalyses.

- Homogenisation of historical data needs to be an evolving process in order to capture structural uncertainty.

- Methodological choices hinge on the research objectives of the resultant dataset.

Summary - II

- Where possible apply all bias adjustments that can be analytically determined (the knowns).
  - SRF, Orbit drift, Orbit decay, fov characteristics
- Biases must be functions of atmospheric state and viewing geometry with comprehensive uncertainty estimates.
- Unkown biases to be treated separately
  - e.g. SRF drift or poor characterisation.
  - SNO
- Details to be confirmed – Close collaboration with ECMWF, NCDC, and others with expert knowledge essential.
- Feedback and comments are welcomed…

Discussion

- Given an opportunity to reprocess IR sounders:
  - Is it worth doing? Yes
  - What lessons have we learnt from previous efforts?
  - How should it be done for maximum benefit?

Last two questions will provide direction.