Extending use of satellite data for reanalyses

Roger Saunders[1], Viju John[1], Graeme Kelly[1] and Paul Poli[2]

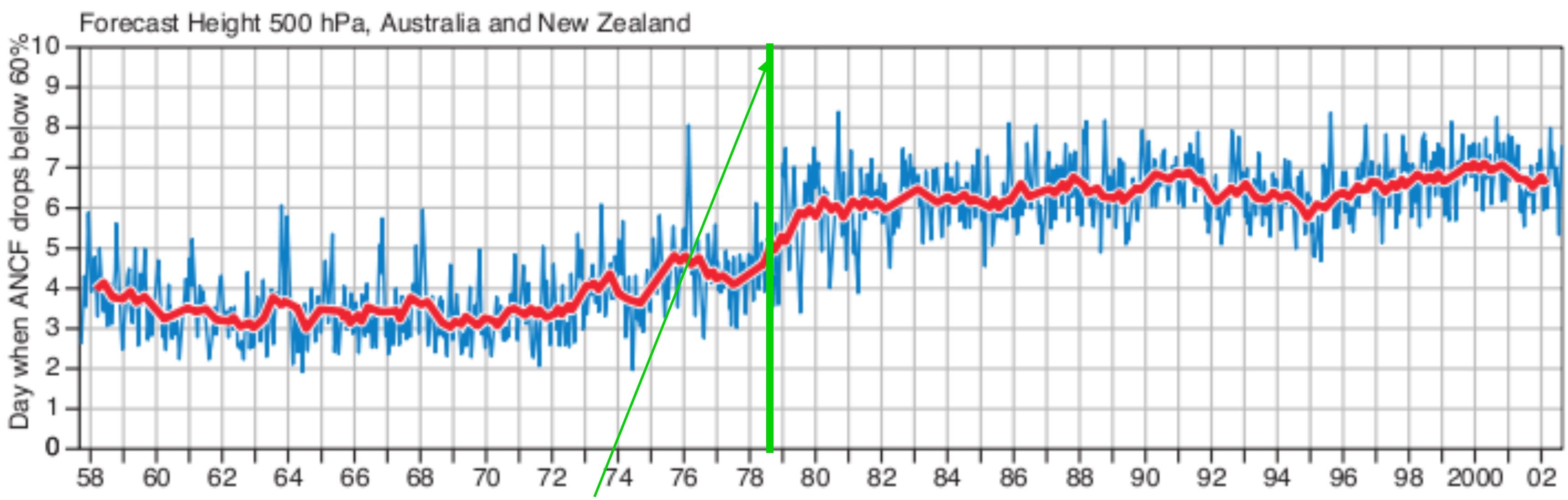
[1]Met Office [2]ECMWF

Extending use of satellite data for reanalyses

- There are many "research" satellites launched in the 1970s which *potentially* could improve reanalyses in that period or at least help to validate them
- Satellite data already used in reanalyses are being reprocessed to provide improved quality data for next generation reanalyses and to fill gaps in data
- We need to ensure future continuity of satellite climate data records
- This talk looks at some options for additional new satellite datasets to be used for reanalyses and what data are being reprocessed

Why bother?
Impact of MSU on Australian/NZ forecasts in ERA-40

Satellite data have been shown to be very valuable in Improving the quality of the analyses in previously data sparse regions. Evidence for this is seen in the forecast skill which improved by 2 days.



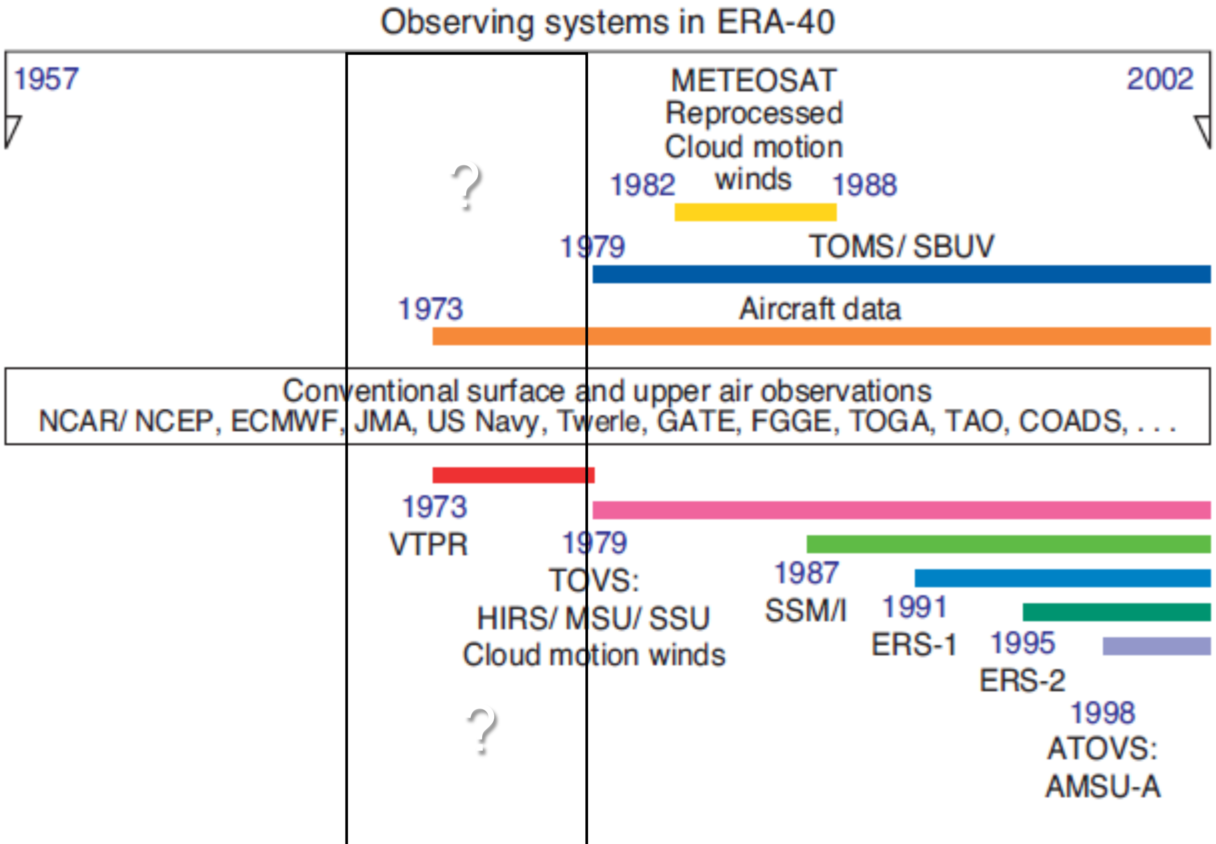
Factors to consider when adopting a new dataset

In order for a dataset to be considered suitable for reanalysis a number of factors must be considered:

- Length and fidelity of data record (>1 year)
- Overlap with other sensors?
- Access to dataset in a readable format
- Quality of dataset (stability, bias, random noise)
- Effective q/c (e.g. clouds, precip, surfaces)
- Availability and complexity of observation operator (e.g. need channel spectral response)

What data is available?

Observations used in ERA-40



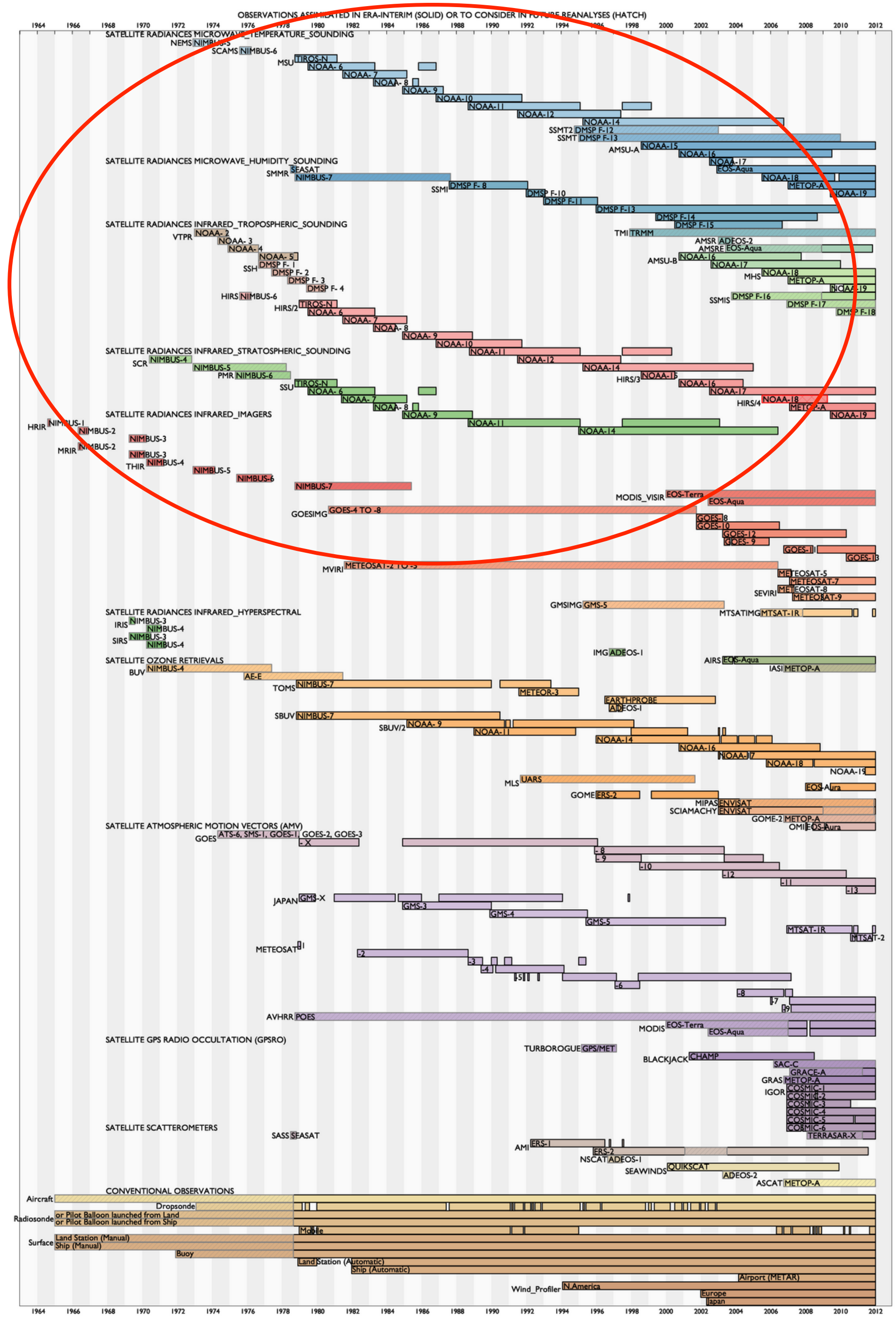
VTPR	Vertical Temperature Profile Radiometer
TOVS	TIROS (Television InfraRed Observational Satellite) Operational Vertical Sounder
HIRS	High-resolution InfraRed Sounder
SSU	Stratospheric Sounding Unit
AMV	Atmospheric Motion Vectors
SSM/I	Special Sensor Microwave/Imager
ERS	ESA Remote-sensing Satellite
ATOVS	Advanced TOVS
AMSU	Advanced Microwave Sounding Unit

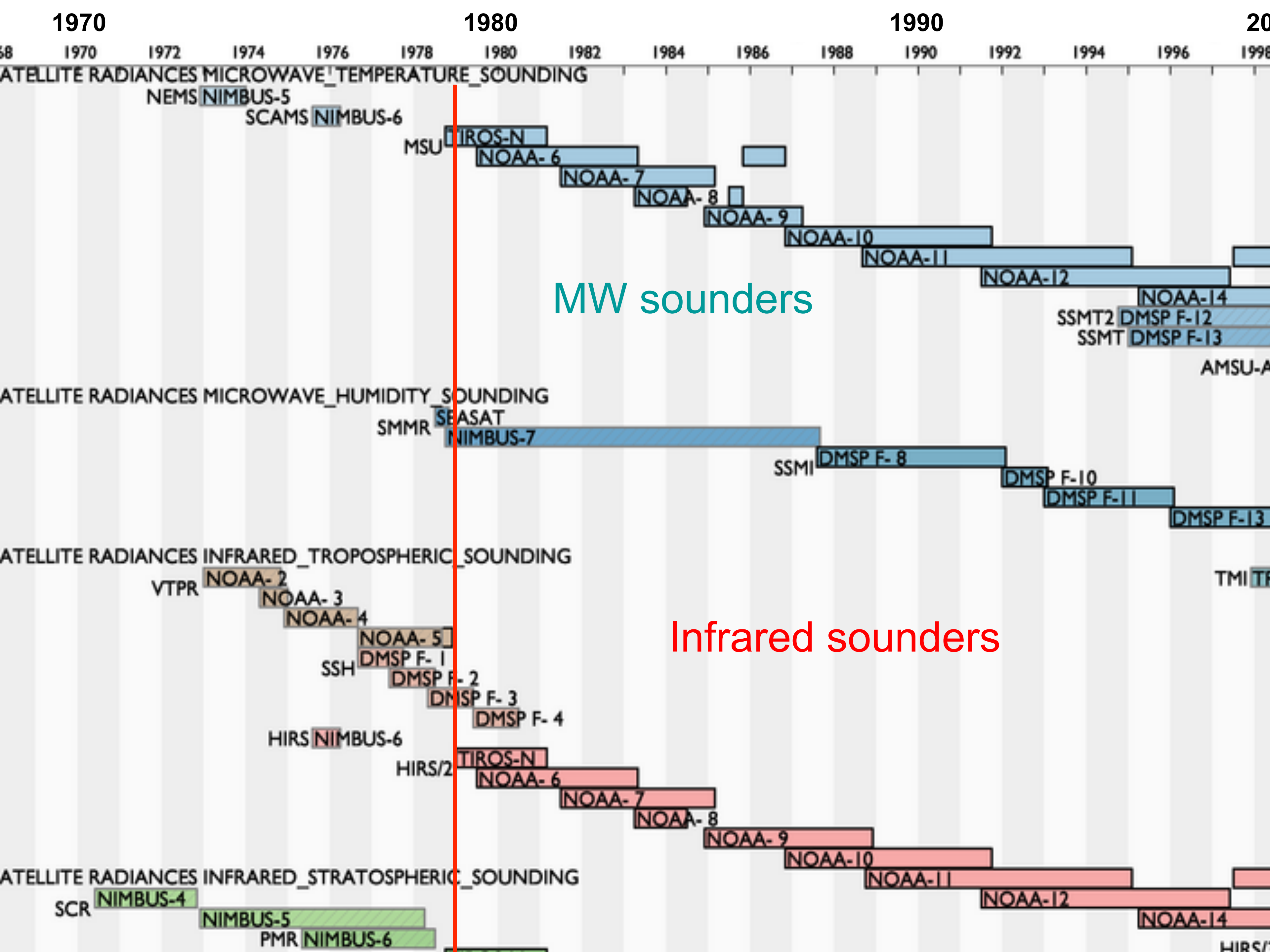
[2] Satellite instrument acronyms

Fig. 2 Schematic illustration of the use of observing systems in ERA-40.

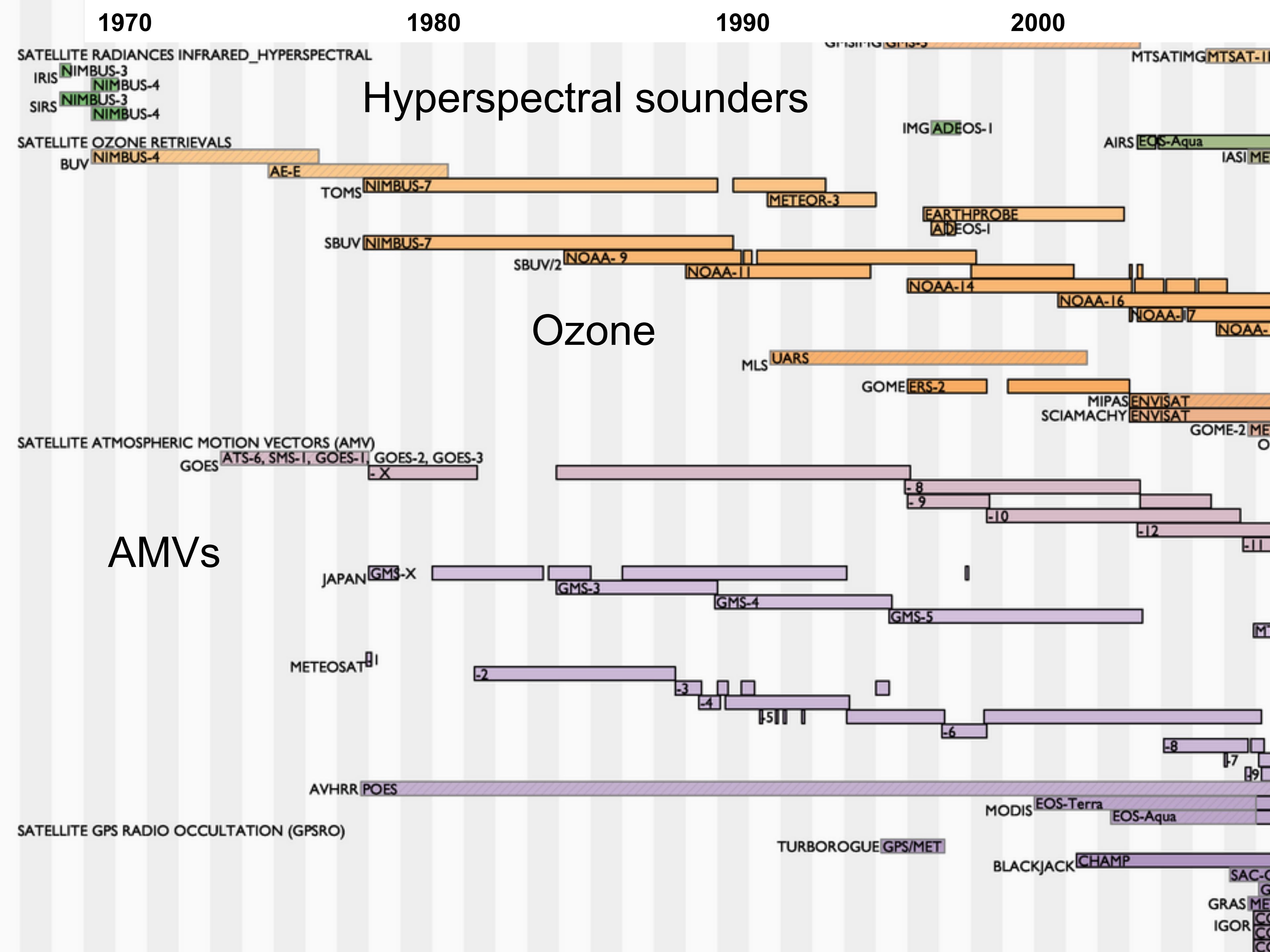
Sounder Radiances

Timeline of satellite observations





1970
1980
1990
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
ATELLITE RADIANCES MICROWAVE_TEMPERATURE_SOUNDING
NEMS NIMBUS-5
SCAMS NIMBUS-6
MSU TIROS-N
NOAA- 6
NOAA- 7
NOAA- 8
NOAA- 9
NOAA-10
NOAA-11
NOAA-12
NOAA-14
SSMT2 DMSP F-12
SSMT DMSP F-13
MW sounders
ATELLITE RADIANCES MICROWAVE_HUMIDITY_SOUNDING
SMMR SEASAT
NIMBUS-7
SSMI DMSP F- 8
DMSP F-10
DMSP F-11
DMSP F-13
ATELLITE RADIANCES INFRARED_TROPOSPHERIC_SOUNDING
VTPR NOAA- 2
NOAA- 3
NOAA- 4
NOAA- 5
SSH DMSP F- 1
DMSP F- 2
DMSP F- 3
DMSP F- 4
HIRS NIMBUS-6
HIRS/2 TIROS-N
NOAA- 6
NOAA- 7
NOAA- 8
NOAA- 9
NOAA-10
NOAA-11
NOAA-12
NOAA-14
TMI
Infrared sounders
ATELLITE RADIANCES INFRARED_STRATOSPHERIC_SOUNDING
SCR NIMBUS-4
NIMBUS-5
PMR NIMBUS-6


1970
1980
1990
2000
Hyperspectral sounders
Ozone
AMVs
SATELLITE RADIANCES INFRARED_HYPERSPECTRAL
IRIS
NIMBUS-3
NIMBUS-4
SIRS
NIMBUS-3
NIMBUS-4
GMS-5
MTSATIMG
MTSAT-1R
IMG
ADEOS-I
AIRS
EOS-Aqua
IASI
SATELLITE OZONE RETRIEVALS
BUV
NIMBUS-4
AE-E
TOMS
NIMBUS-7
METEOR-3
EARTHPROBE
ADEOS-I
SBUV
NIMBUS-7
SBUV/2
NOAA- 9
NOAA-11
NOAA-14
NOAA-16
NOAA-17
MLS
UARS
GOME
ERS-2
MIPAS
ENVISAT
SCIAMACHY
ENVISAT
GOME-2
SATELLITE ATMOSPHERIC MOTION VECTORS (AMV)
GOES
ATS-6, SMS-1, GOES-1, GOES-2, GOES-3
- X
- 8
- 9
-10
-12
-11
JAPAN
GMS-X
GMS-3
GMS-4
GMS-5
METEOSAT
-1
-2
-3
-4
-5
-6
-8
-7
-9
AVHRR
POES
MODIS
EOS-Terra
EOS-Aqua
SATELLITE GPS RADIO OCCULTATION (GPSRO)
TURBOROGUE
GPS/MET
BLACKJACK
CHAMP
GRAS
IGOR

IRIS (Nimbus-3, -4) NEED RTM	Apr 1970 - Jan 1971	NSSDC, ftp	2 recent papers using IRIS data
SIRS (Nimbus-3, -4) NEED RTM	1969-1972 (1.8)	Nimbus-4 radiances at NSSDC, Mag tape	Nimbus-4 being transferred to ftp
SCR (Nimbus-4, -5) NEED RTM	1970-1973, 1972-1974 (4.5)	1. NSSDC, Mag tape 2. Oxford Physics, CD	1. Should be on ftp by late 2011 2. Contains only gridded radiances for N-4
SAMS (Nimbus-7) NEED RTM	1978-1983	1. Oxford Physics, CD 2. NSSDC, unknown media	
PMR (Nimbus-6) NEED RTM	1975-1978	At Met Office, CD	
SSU NEED IMPROVED RTM	1978-2006	NOAA	Cell pressure changes over time: should be modelled by RTM
ITPR (Nimbus-5) NEED RTM	1972-1976 ?	NSSDC, unknown media	From Bill Smith "ITPR operation was very intermittent because of a scan mirror motor problem".
HIRS (Nimbus-6) NEED RTM	1975-1976	NSSDC, Mag tape	Should be on ftp by late 2011. From Bill Smith: "HIRS SW channels became noisy after a couple months of operation but the most important LW data remained useful throughout its lifetime"
VTPR (NOAA-2/ITOS-D,-3/-F,-4/-G,-5/-E2) CHECK RTM	1972-1979 (6.3)		
SSH actually an advanced VTPR with 16 channels (DMSP F-1,-2,-3,-4) NEED RTM	1976-1980 ?	NSSDC, Mag tape	Have tapes of DMSP but don't know if VTPR is on them. No plans to read tapes.
MFR (DMSP F-1,-2,-3,-4) NEED RTM	1976-1980 ?	NSSDC, Mag tape	Have tapes of DMSP but don't know if MFR is on them. No plans to read tapes.
HIRS/2,/3,/4	1978-present	NOAA	

A “new” HIRS to assimilate

Met Office
Hadley Centre

Channel	Characteristics						
Channel Number	Central Wave Number (cm^{-1})	Interval Between 50% Response Points (cm^{-1})	Noise Equivalent Radiance ($mw/m^{-2}ster\ cm^{-1}$)		Noise Equivalent Temperature (NEΔT) Source Temp. = 290°K		
			T_D = 118°K	T_D = 124°K	T_D = 118°K	T_D = 124°K
1	668	2.8	3.0	6.0	1.90	3.80
2	679	13.7	0.66	1.5	0.41	0.94
3	690	12.6	0.45	0.75	0.28	0.47
4	702	15.9	0.27	0.44	0.17	0.27
5	716	17.5	0.52	0.85	0.32	0.52
6	733	17.6	0.23	0.38	0.14	0.23
7	749	18.4	0.27	0.42	0.16	0.26
8	900	34.6	0.19	0.30	0.12	0.19
9	1224	63.4	0.15	0.24	0.14	0.23
10	1496	87.6	0.13	0.19	0.21	0.31
11	2190	20.6	0.012	0.012	0.13	0.13
12	2212	22.5	0.003	0.003	0.04	0.04
13	2242	21.6	0.006	0.006	0.08	0.08
14	2275	35.2	0.002	0.002	0.03	0.03
15	2357	23.0	0.003	0.003	0.06	0.06
16	2692	296.9	0.001	0.001	0.06	0.06
17	14,443	892.2	–	–	–	–

Microwave sounders

Met Office
Hadley Centre

NEMS (Nimbus-5) NEED RTM	1972-1973	NSSDC, Microfiche	Some NEMS data in Bldg 28. No details
ESMR (Nimbus-5) NEED RTM	1972-1976	NSIDC, ftp	Gridded dataset only?
SCAMS (Nimbus-6) NEED RTM	1975-1976	NSSDC, Mag tape	Should be on ftp by late 2011
MSU	1978-2006	NOAA, ftp	Reprocessed by NOAA/STAR
AMSUA	1998-present	NOAA, NASA for EOS-Aqua, EUMETSAT for METOP	Reprocessed by NOAA/STAR (except NASA EOS-Aqua)
AMSUB & MHS	1998-present	NOAA, NASA for EOS-Aqua, EUMETSAT for METOP	
SMMR (Nimbus-7) NEED RTM	1978-1987	1. NSSDC, Mag tape 2. NSIDC, ftp	1. No plans to recover Nimbus-7 data for now. 2. Gridded radiance only?
SSM/I	1987-present	1. RSS via NCDC 2. CM-SAF	RSS currently generating recalibrated radiance dataset V7, to be transferred to NCDC. Should be available in a couple of months.
SSM/T (-1 and -2) NEED RTM FOR SSM/T-1	1994-?	Met Office, ftp	
SSM/I-S	2005-present		
AMSR-E (EOS-Aqua)	2002-2011	NASA	
WINDSAT	2003-present	NRL	

Atmospheric motion vectors

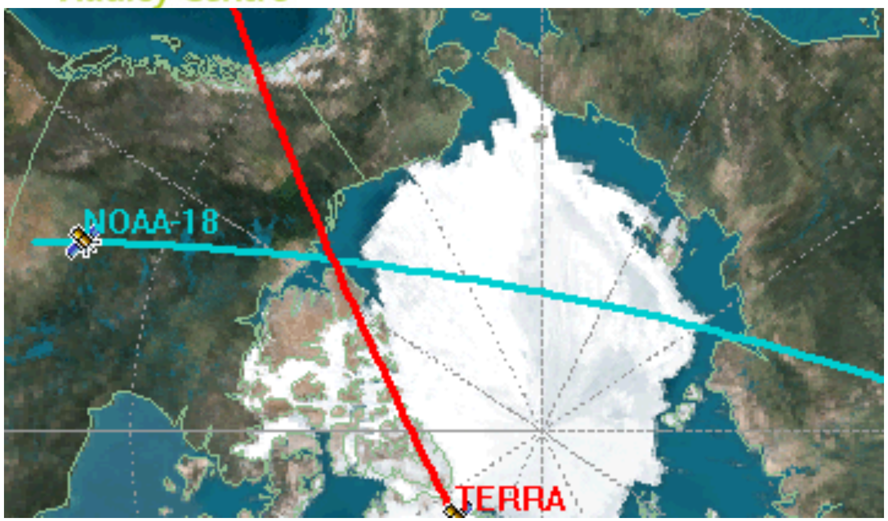
METEOSAT	1977-present	EUMETSAT	EUMETSAT reprocessing ongoing for all data from METEOSAT-2 (1981) onwards in ERA-CLIM
ATS, SMS	1960s and 1970s	CIMSS, Mag Tapes	Some voluntary data rescue at CIMSS. How much longer before the last persons able to read those analog tapes retire?
GOES	1978-present	CIMSS, ftp	Reprocessing plans unclear
GMS, GOES-9, MTSAT	1979,1987-present	JMA	Reprocessing complete
AVHRR METOP	2006-present	EUMETSAT	EUMETSAT reprocessing ongoing in ERA-CLIM
AVHRR NOAA	1978-present	CIMSS, ftp	Setting up a reprocessing system, will run by November 2011
MODIS	1999-present	NASA	Systematic reprocessing for low-level radiances (?), but AMV reprocessing needed

How to assess new data?

Global Satellite Intercalibration Calibration System
Simultaneous Nadir Overpass (SNO) Method

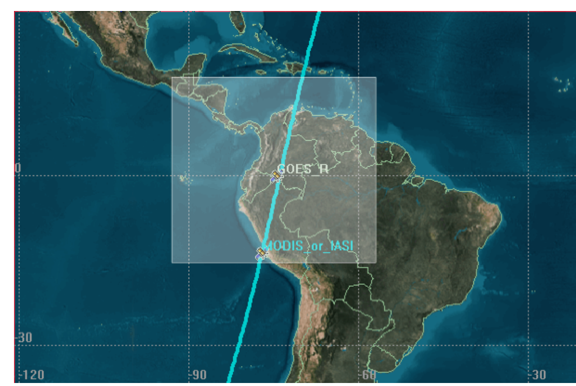
Met Office
Hadley Centre

POES intercalibration



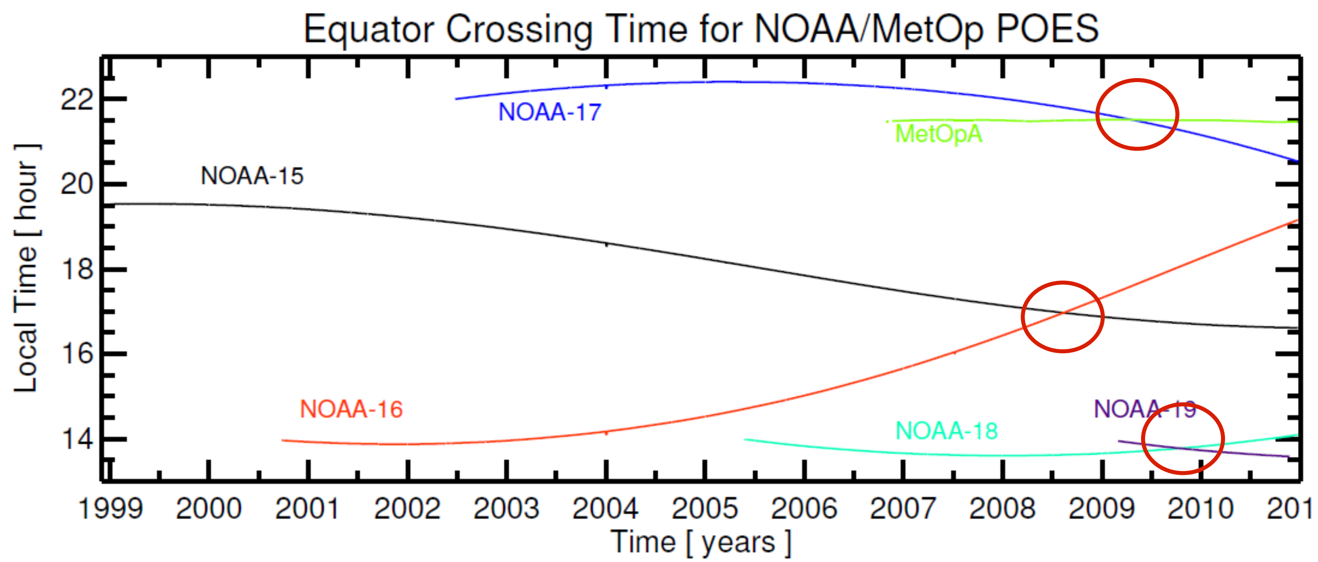
- Useful for remote sensing scientists, climatologists, as well as calibration and instrument scientists
- Potential for (A)ATSR and geo or polar matches

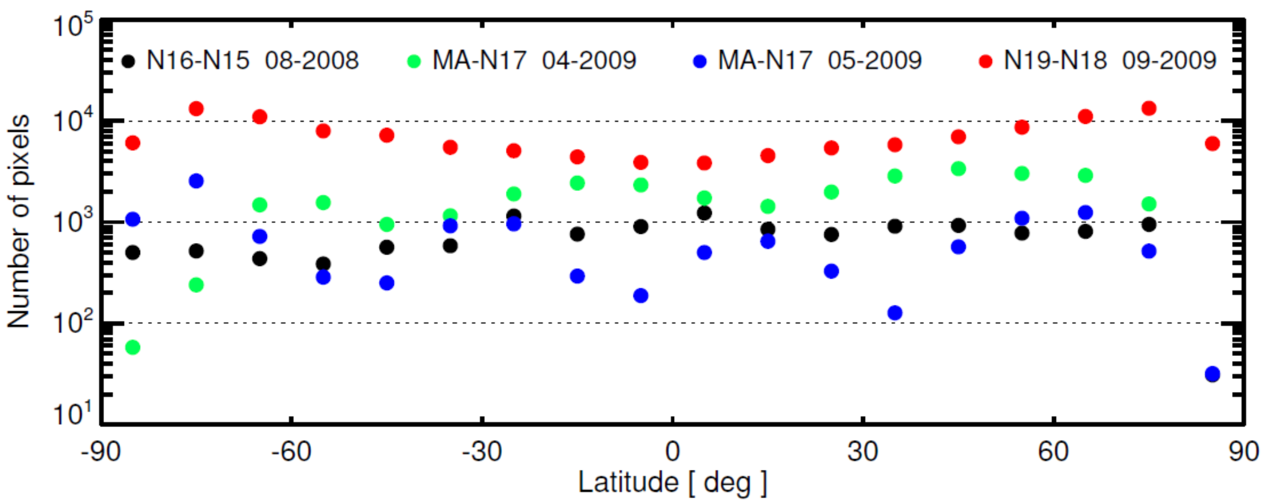
- Has been applied to microwave, vis/nir, and infrared radiometers for on-orbit performance trending and climate calibration support
- Capabilities of 0.1 K for sounders and 1% for vis/nir have been demonstrated in pilot studies



GOES vs. POES

Global SNOs





SNOs occur over all latitudes when Eq. Xing times are identical

John et al., (in press) *J. Geophys. Res.*

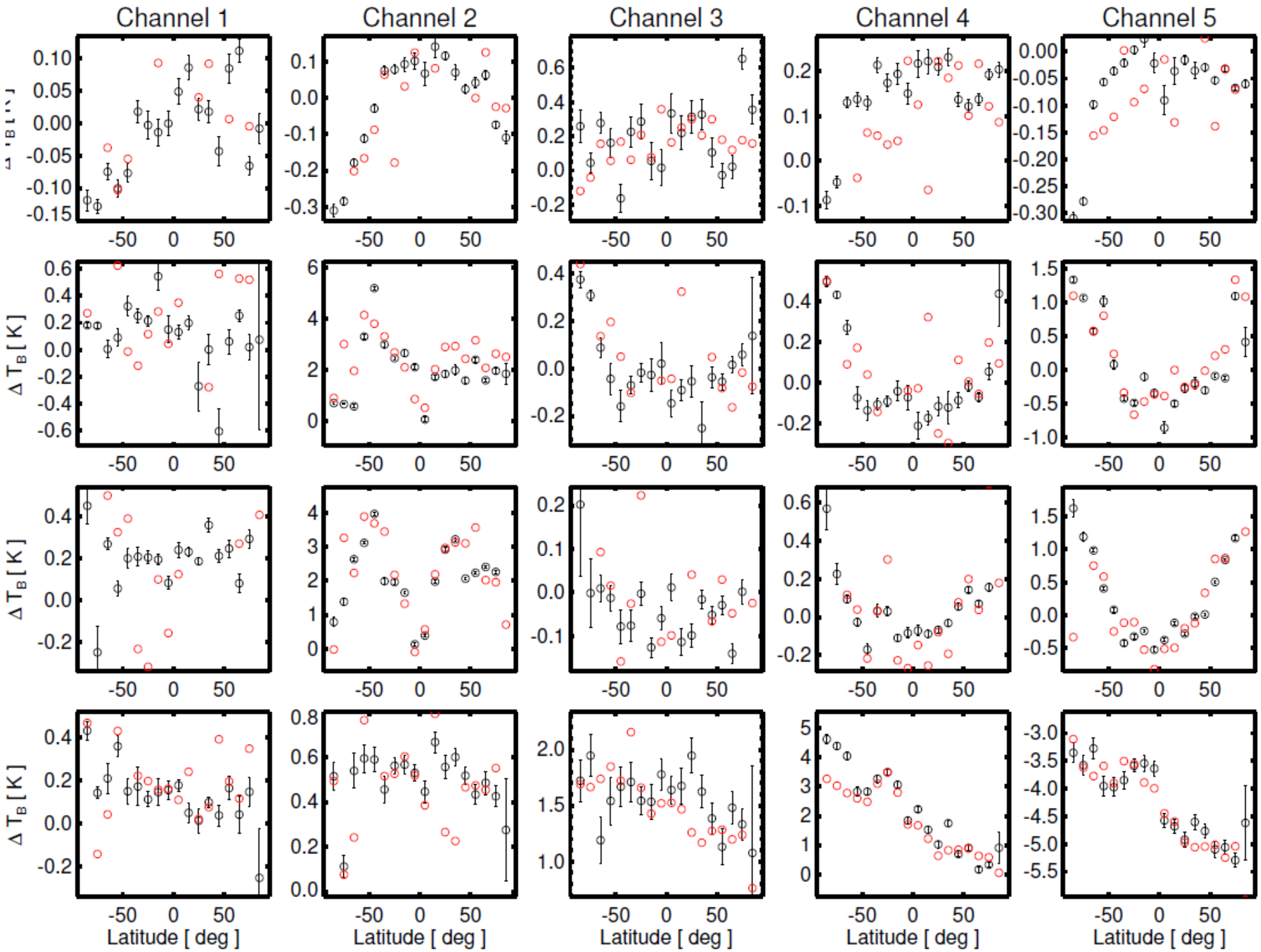
Distribution of bias for AMSU-B/MHS

N19-N18 2009-09

MA-N17 2009-05

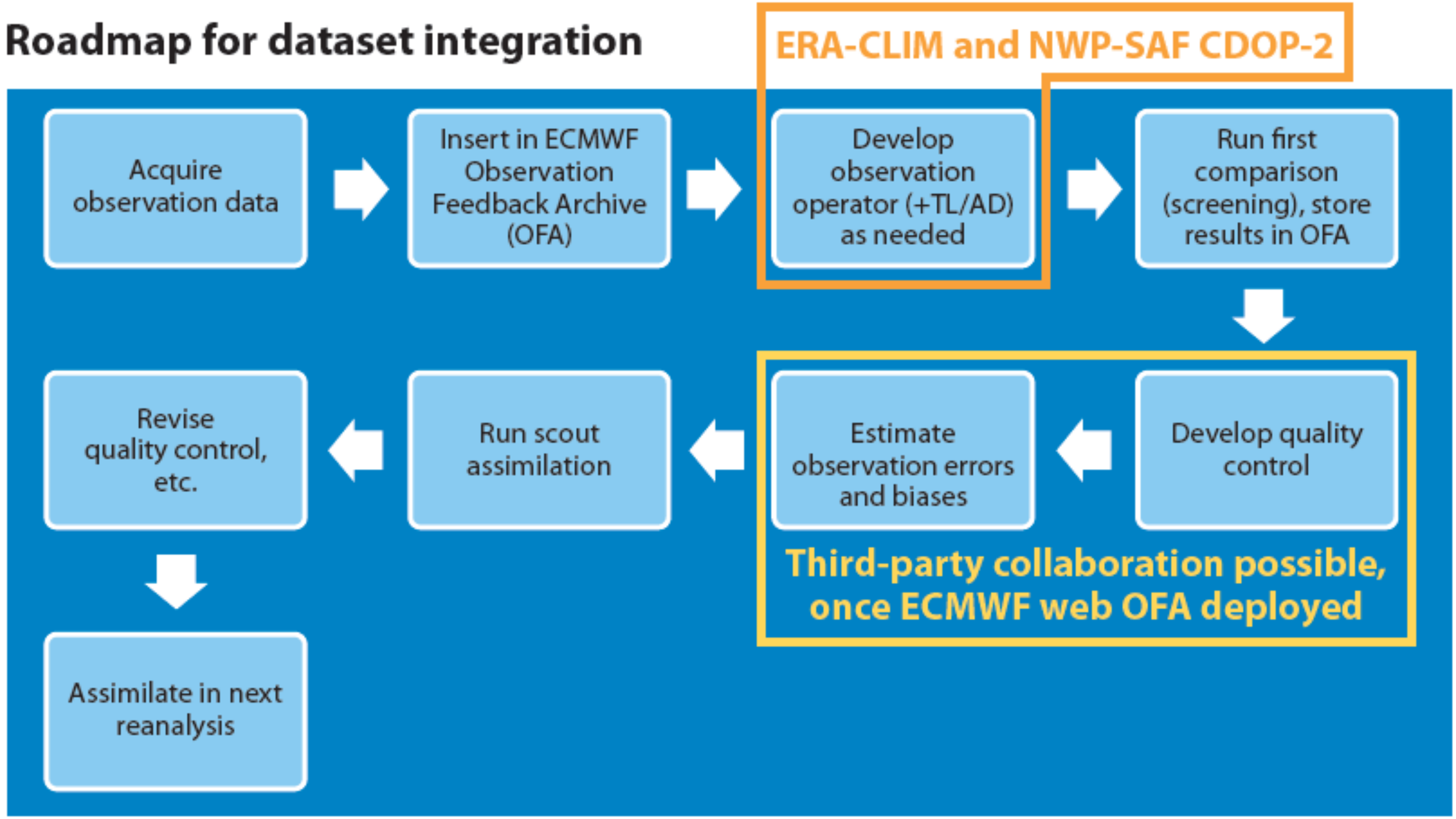
MA-N17 2009-04

N16-N15 2008-08

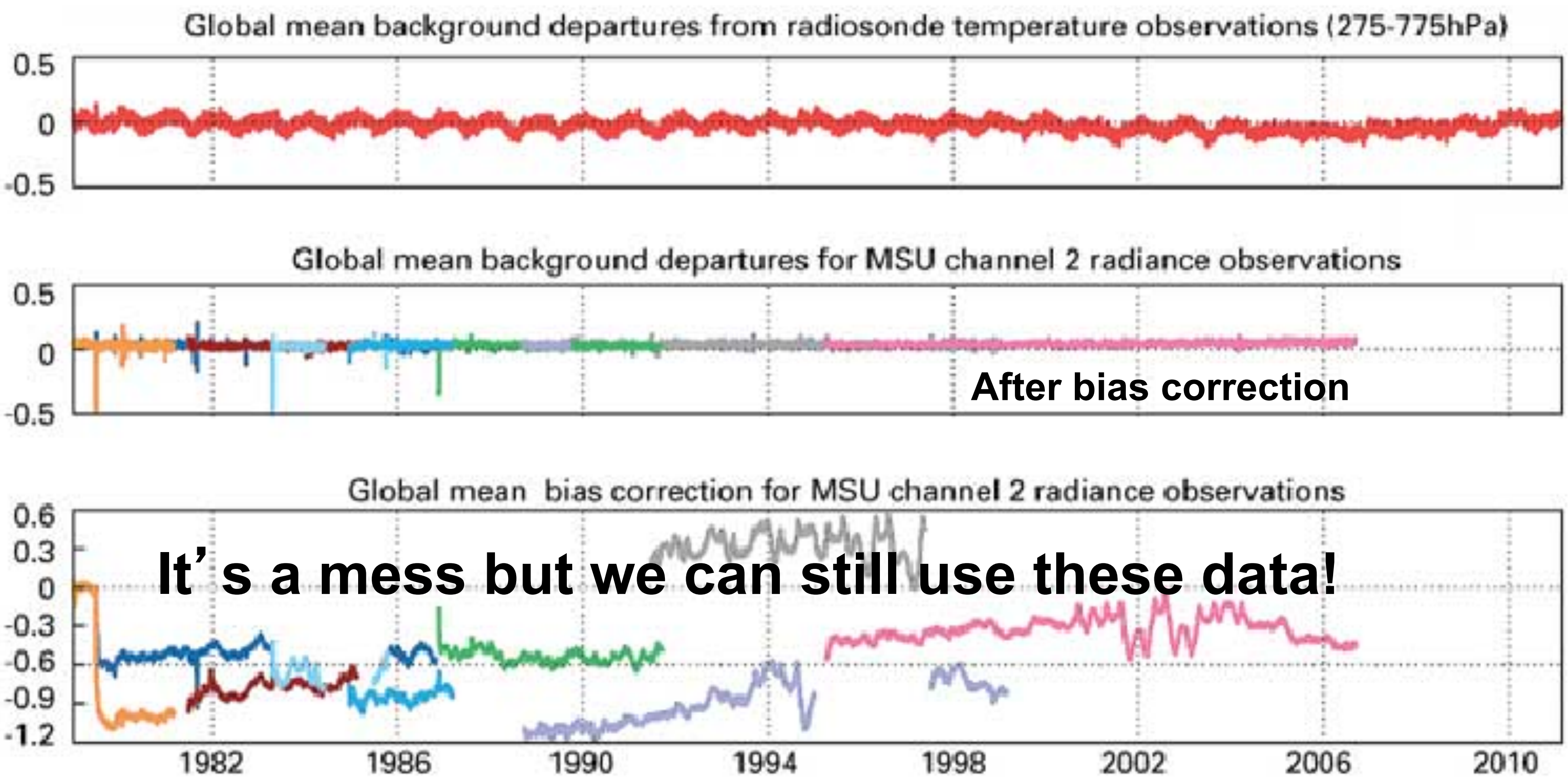


John et al., (in press) *J. Geophys. Res.*

Assessing observations for use in reanalyses



Bias for radiosonde and MSU satellite obs



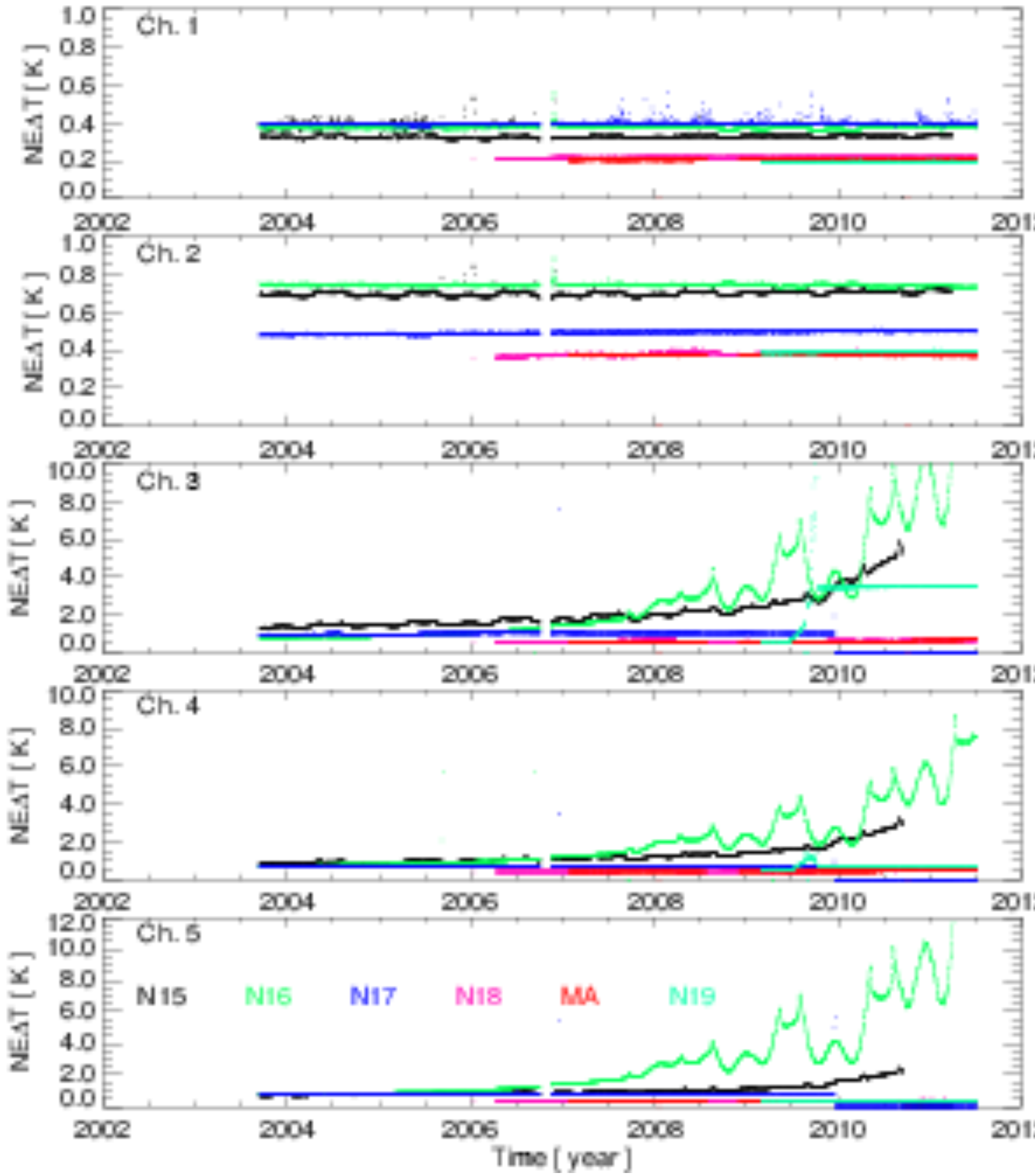
From A. Simmons

AMSU-B/MHS Instrument noise

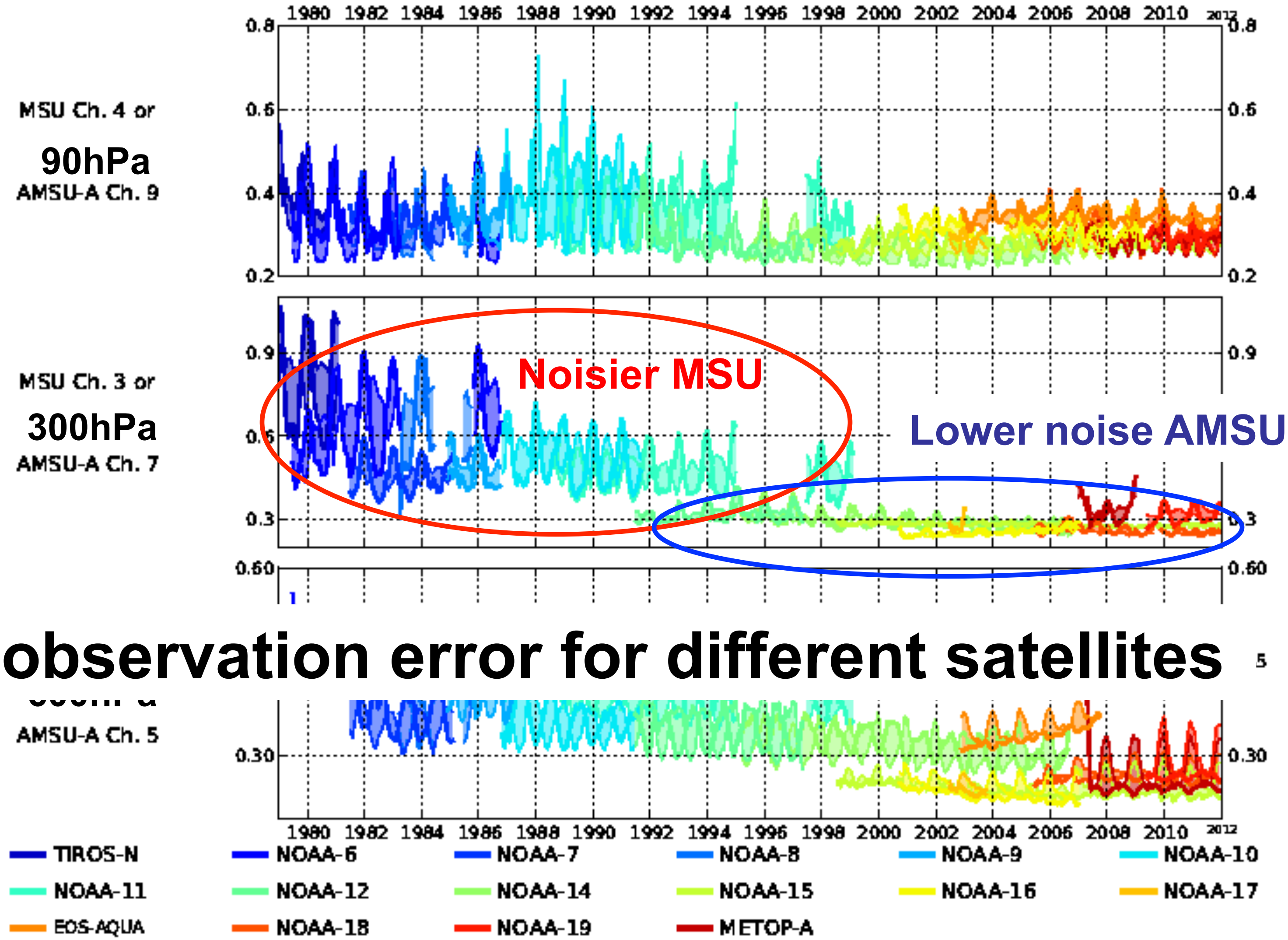
- Quality of the sounding data has to be analysed before homogenisation

- Select data from each satellite based on channel performance (e.g., NEdT) by looking at black body.

This is completely independent from the reanalysis

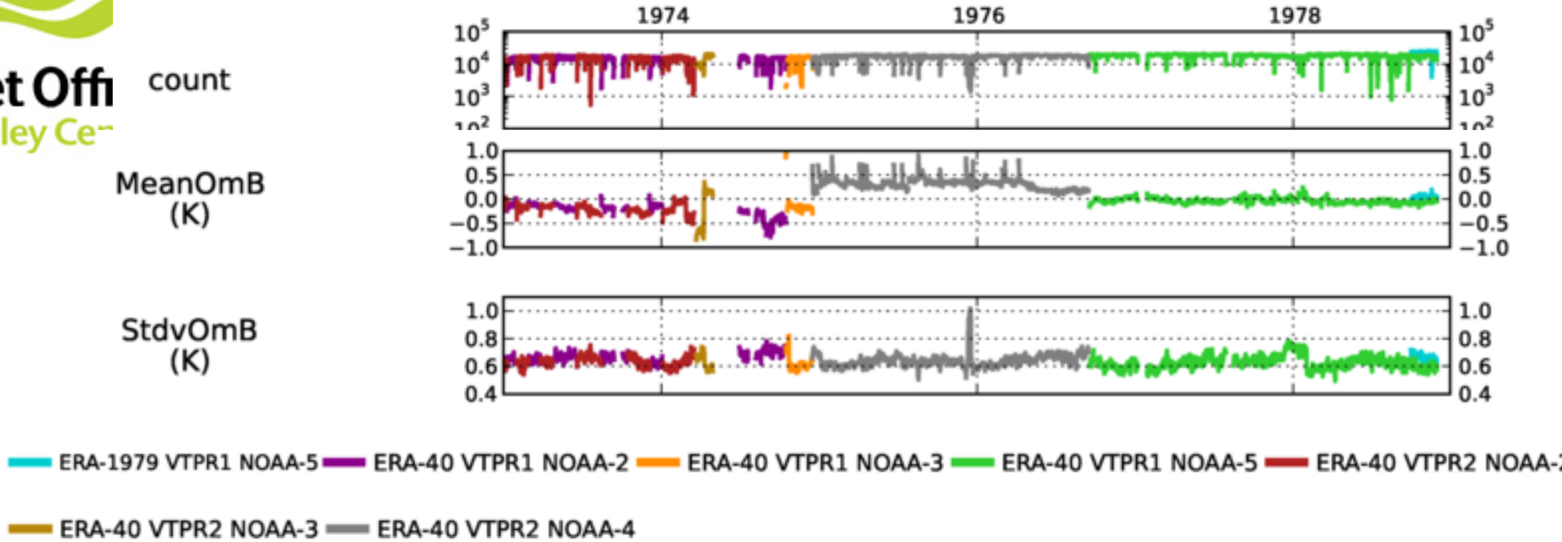


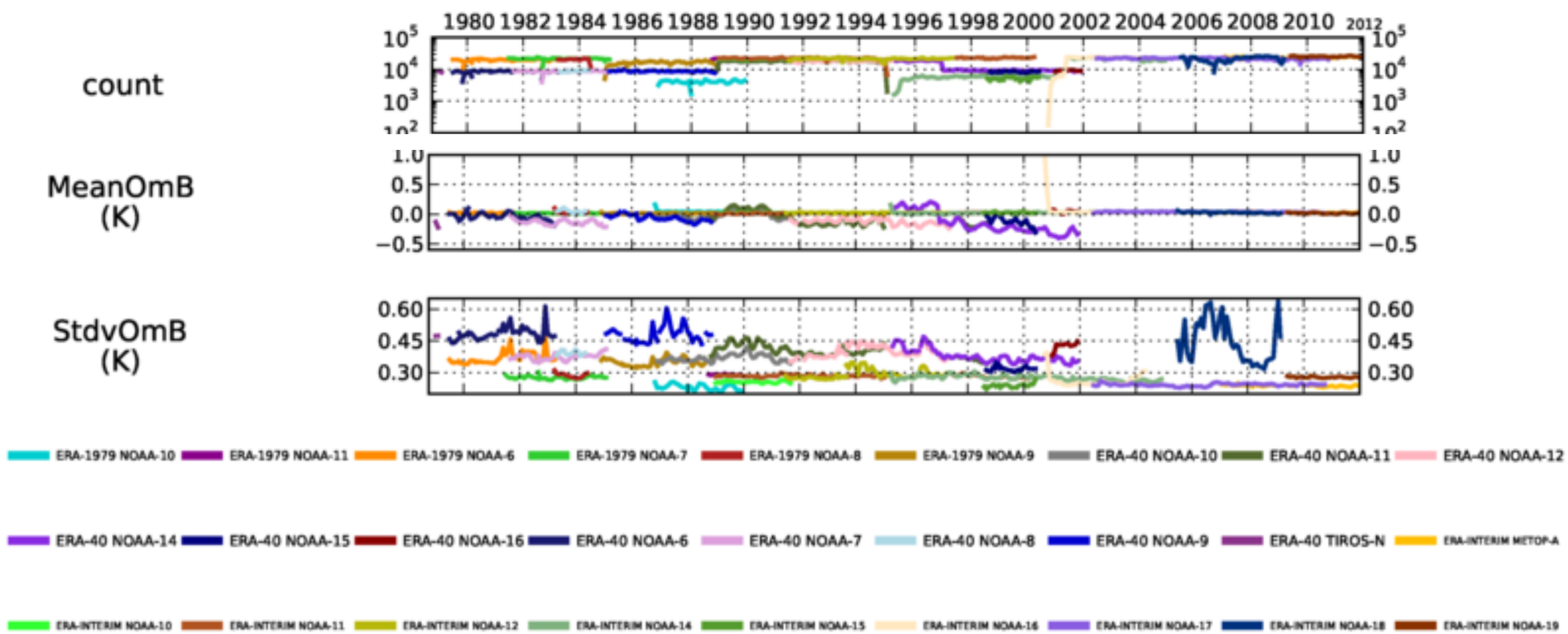
Time series of monthly sdev of O-B stats before bias correction for MSU and AMSU sounding channels



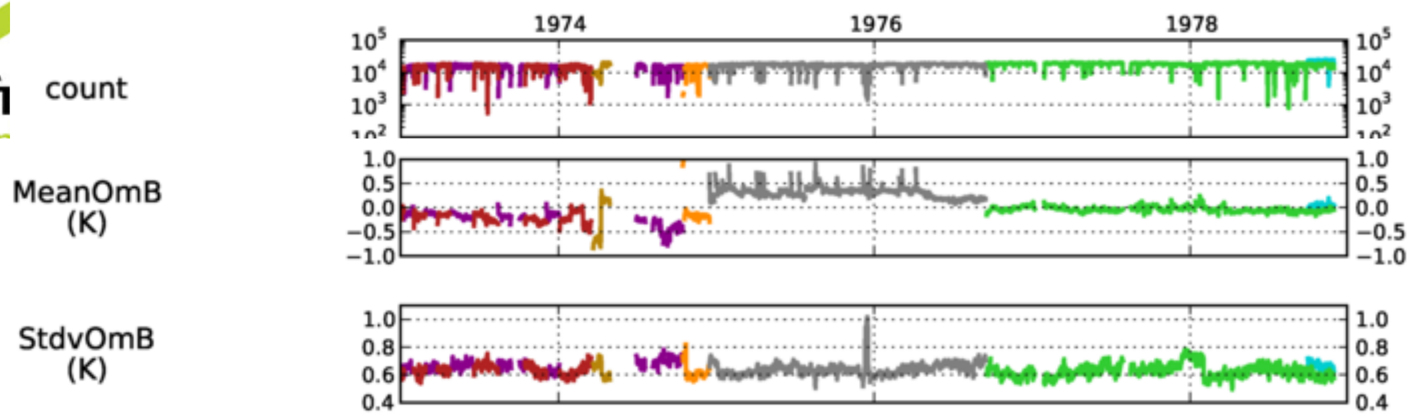
Vary observation error for different satellites

HIRS and VTPR 400hPa channels

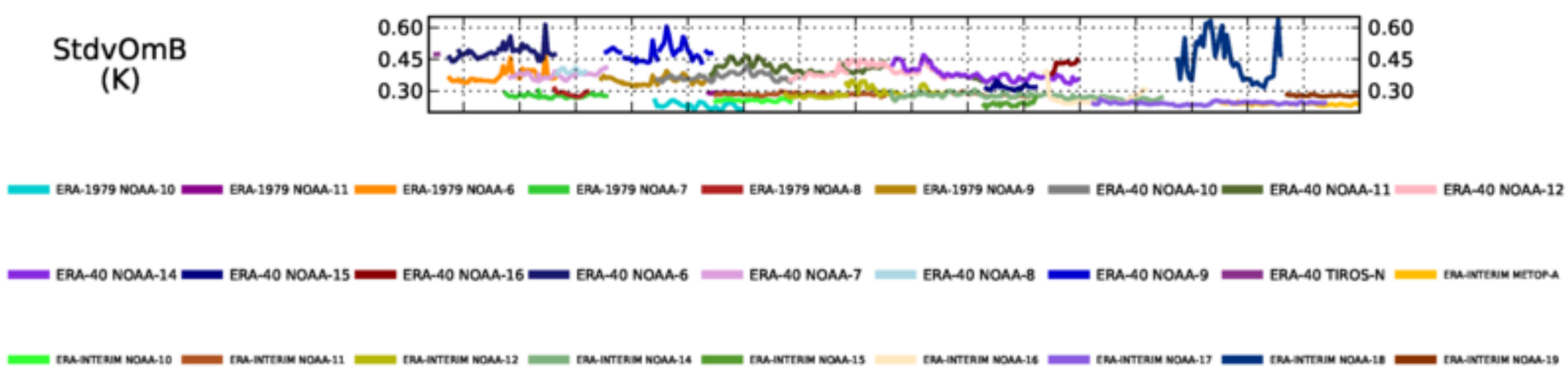




HIRS and VTPR 400hPa channels



- HIRS instrument noise for good instruments (0.3K) appears to be half VTPR noise (~0.6K). In ERA-40 observation errors for HIRS-4 was 0.6K and VTPR-4 was 0.7K.

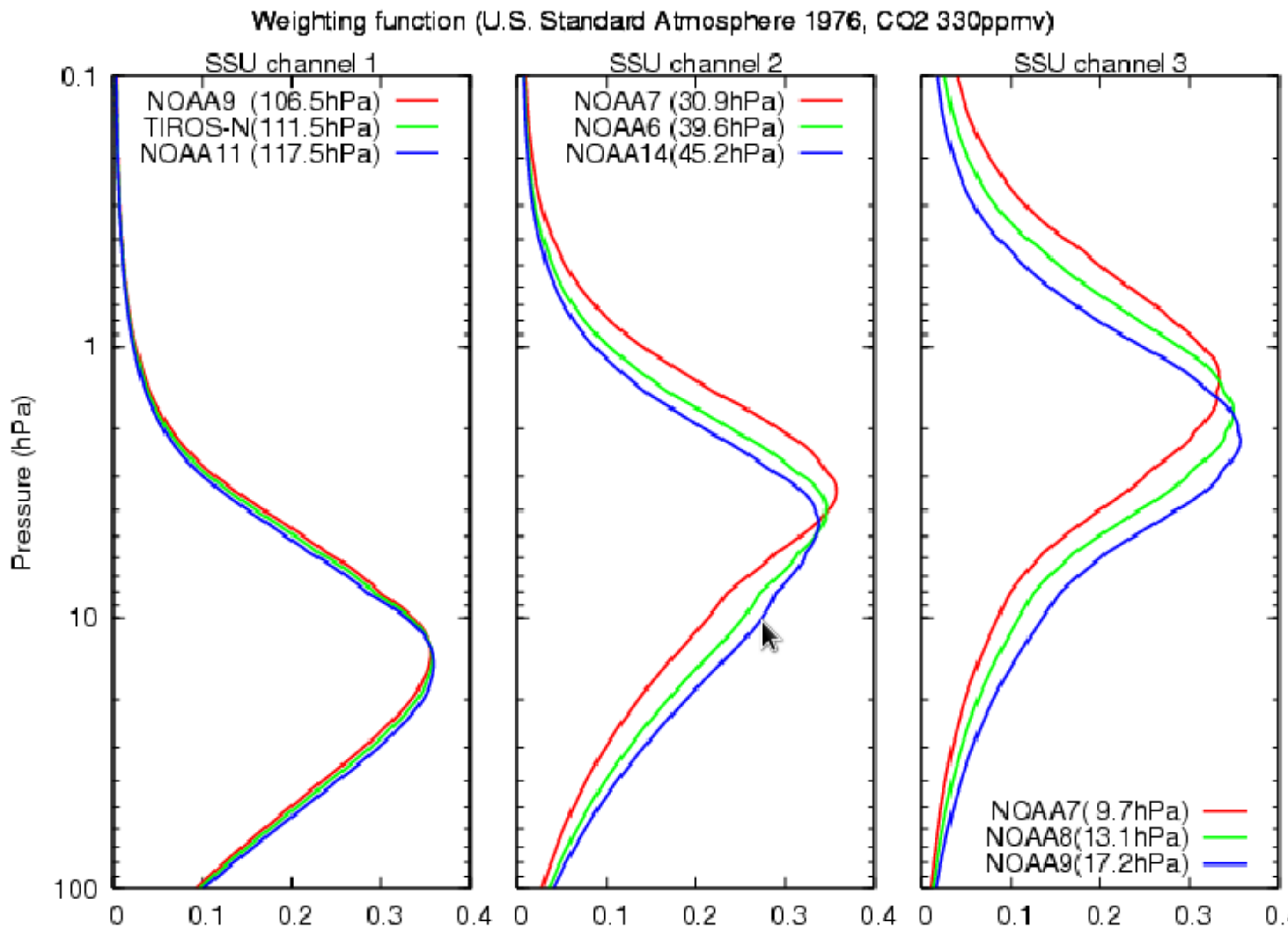


ERA-Clim Satellite Observation operators

Provision of updated or new RT coefficients for:

- SSU (based on latest spectroscopy and allowing for cell pressure) in progress thanks Shinya!
- PMR follows SSU
- VTPR recomputed with new spectroscopy done
- SSM/T2 done
- SSM/T, SCAMS, SMMR in progress

Impact of cell pressure on SSU weighting functions

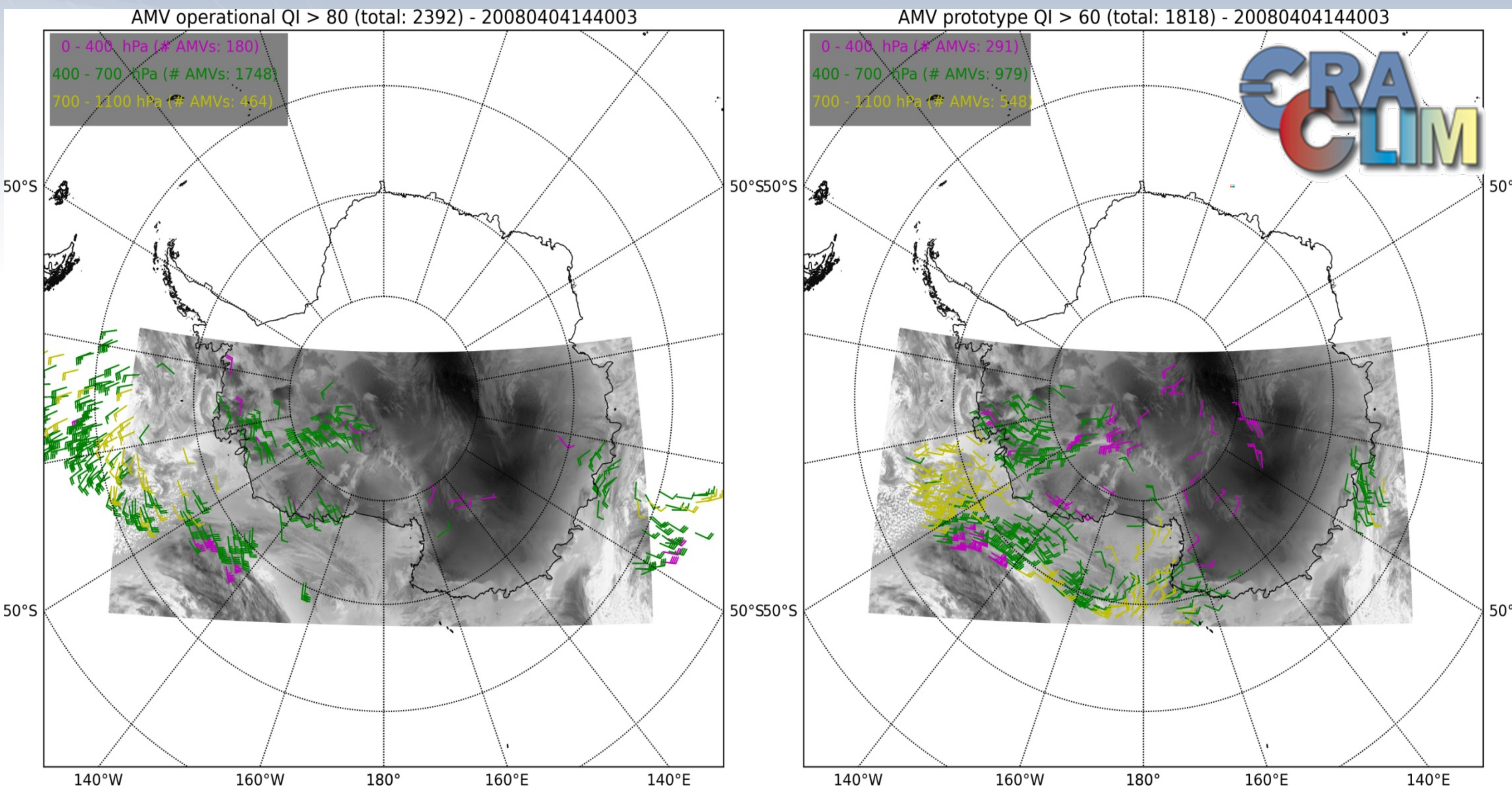


Instru-ment	Characteristics	Immediate concern	Recom-mendation
NEMS	Microwave spectrometer, with two water vapour channels near 22 GHz (5 mm) and three channels near 59 GHz (10 mm), spatial resolution 180 km at nadir	Nadir-viewing only, data on microfiche	**Reject for now**
SCAMS	Microwave spectrometer, with one water vapour channel near 22 GHz (5 mm), three channels near 59 GHz (10 mm), one window channel, spatial resolution 150 km at nadir	Data recovery in process by NSSDC.	**Consider for assimilation**
SSM/T	Microwave temperature sounders precursors to AMSU-A and AMSU-B but with bigger fields-of-view. Met Office preparing a homogenized data for ERA-CLIM.	RT forward model needed for SSM/T	**Assimilate**
SMMR	Microwave radiometer, ten channels: dual-polarization measurements at 6.63, 10.69, 18.0, 21.0, and 37.0 GHz, spatial resolution 150 km at nadir	Raw radiance data not found	**Keep looking for data**
SSH	Discrete filter radiometer, six channels in the 15 micron CO_2 band, one window channel, eight water vapour channel in the 22–30 micron band, one channel in the 10 micron ozone band	Data lost forever?	**Keep looking for data**
HIRS on Nimbus-6	Discrete filter radiometer, seven channels in the 15 micron CO_2 band, two window channels, two water vapour channels, five channels in the 4.3 micron band, spatial resolution 25 km at nadir	Data recovery in process by NSSDC. Digital version of the SRF not found.	**Assimilate**
SCR	Radiometer observing through a pressurized optical cell, six channels in the 15 micron CO_2 band, spatial resolution 112–160 km at nadir (Nimbus-5: eight channels in the 15 micron CO_2 band, three window channels, one water vapour channel at 18.6 microns, spatial resolution 30 km at nadir)	RT coefficients challenging	**Validate**
PMR	Radiometer observing through a pressurized optical cell	RT coefficients challenging	**Assimilate**
HRIR	Visible and infrared imager, 8 km spatial resolution at nadir, 3.5–4 micron channel (and also 0.7–1.3 for Nimbus-3)	Digital version of SRF not found	**Validate**
MRIR	Infrared imager, five channels including a water vapour channel in the 6.7 micron band	Digital version of SRF not found	**Validate**
THIR	Infrared imager, one window channel and one water vapour channel in the 6.7 micron band	Only JPEG images available, raw radiance data lost forever?	**Keep looking for data**
IRIS	Michelson interferometer, covering 5–20 microns with 5 cm^{-1} normalized apodized spectral resolution (Nimbus-4: 6.25–25 microns, 2.8 cm^{-1} resolution), nadir spatial resolution 144 km	Short time period, calibration biases	**Validate**
SIRS	Grating spectrometer, covering 11–15 microns (Nimbus-4: 11–36 microns), nadir spatial resolution 220 km	Narrow swath (up to 12 degrees only from nadir)	**Consider for assimilation**
AVHRR	Imager on polar orbiters, atmospheric motion vector (wind) retrievals at the poles. EUMETSAT and CIMSS working on reprocessing.	Reprocessing not complete yet	**Assimilate**
SeaSat	First scatterometer ever. Suspicious end-of-life.	Very short dataset (97 days)	**Validate**
NSCAT	Scatterometer from U.S.	Short dataset (9 months)	**Assimilate**

Reprocessing Satellite Data

- NASA MEaSUREs Program (SBUV, TOMS…), JPL
- NOAA STAR (AVHRR, AMSU-A, SST,..)
- ESA (GlobXXX, Climate Change Initiative)
- EUMETSAT (Meteosat, AVHRR AMVs, radiances)
- SCOPE-CM (AMVs, albedo, UTH, SSM/I,..)
- JMA (MTSAT/GMS AMVs + radiances)

Example: Two Wind Vector Processors Results Antarctic 14 April 2008, 14:03 UTC



ESA CCI 13 ECVs

Atmosphere	**Surface**	Air temperature; Precipitation, Pressure, Surface radn budget, Wind
	Upper Air	Clouds, Wind, Earth Radn Budget Upper air temp, water vapour
	Composition	Carbon dioxide, methane & GHGs Ozone, Aerosol properties
Ocean	**Surface**	SST, Sea-level, Sea-ice, Ocean colour Sea state, Salinity, CO_2 partial pressure
	Sub-surface	Temperature, Salinity, Current, Nutrients, Carbon, Ocean Tracers, Phytoplankton
Terrestrial	Glaciers & Ice caps, Land cover, Fire disturbance, FaPAR, LAI, Albedo, Biomass,Lake levels, Snow cover, Soil moisture, Water use, Ground water, River discharge, Permafrost, Seasonally frozen ground, Ice Sheets	

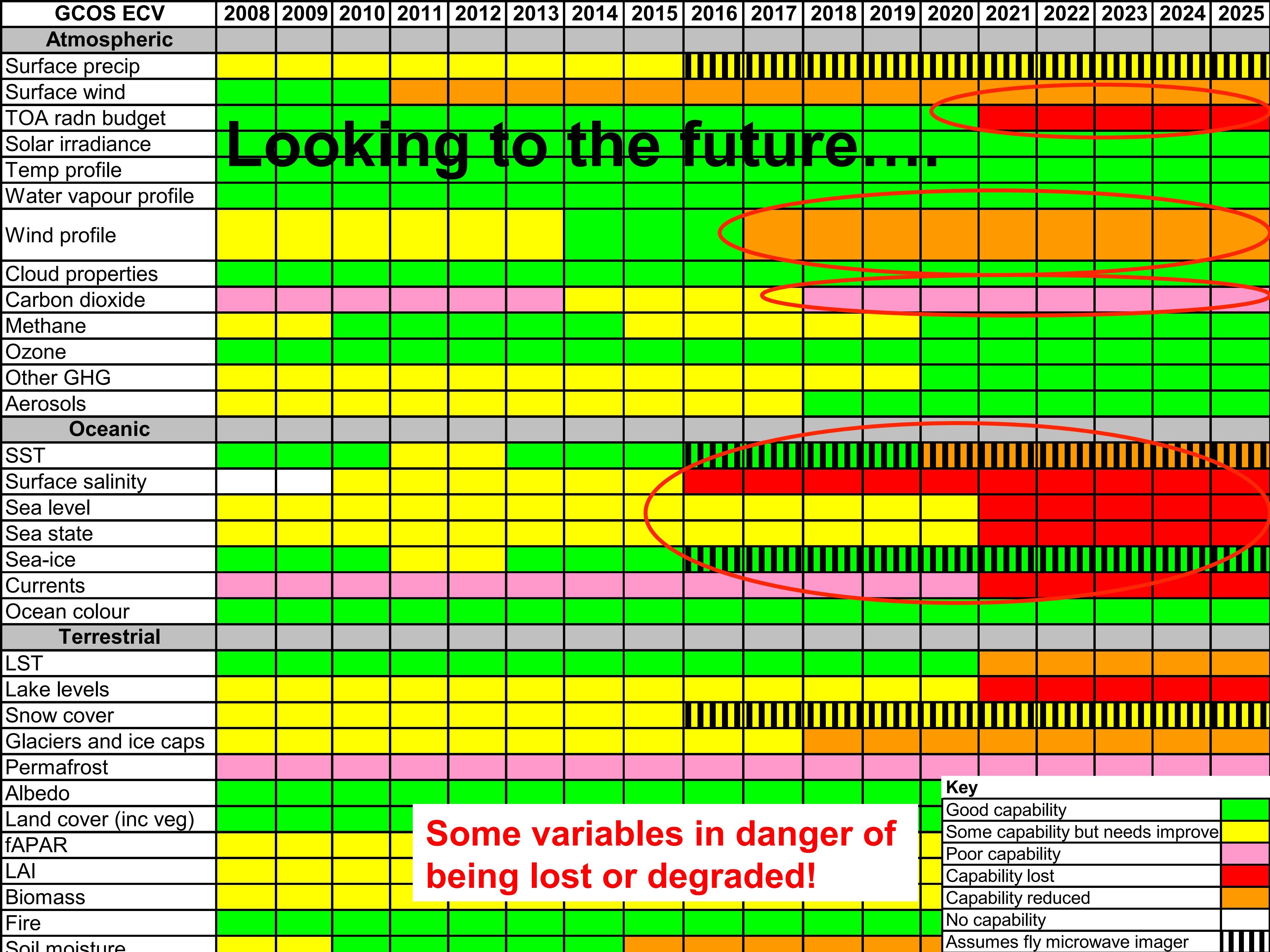
Survey of early satellite data

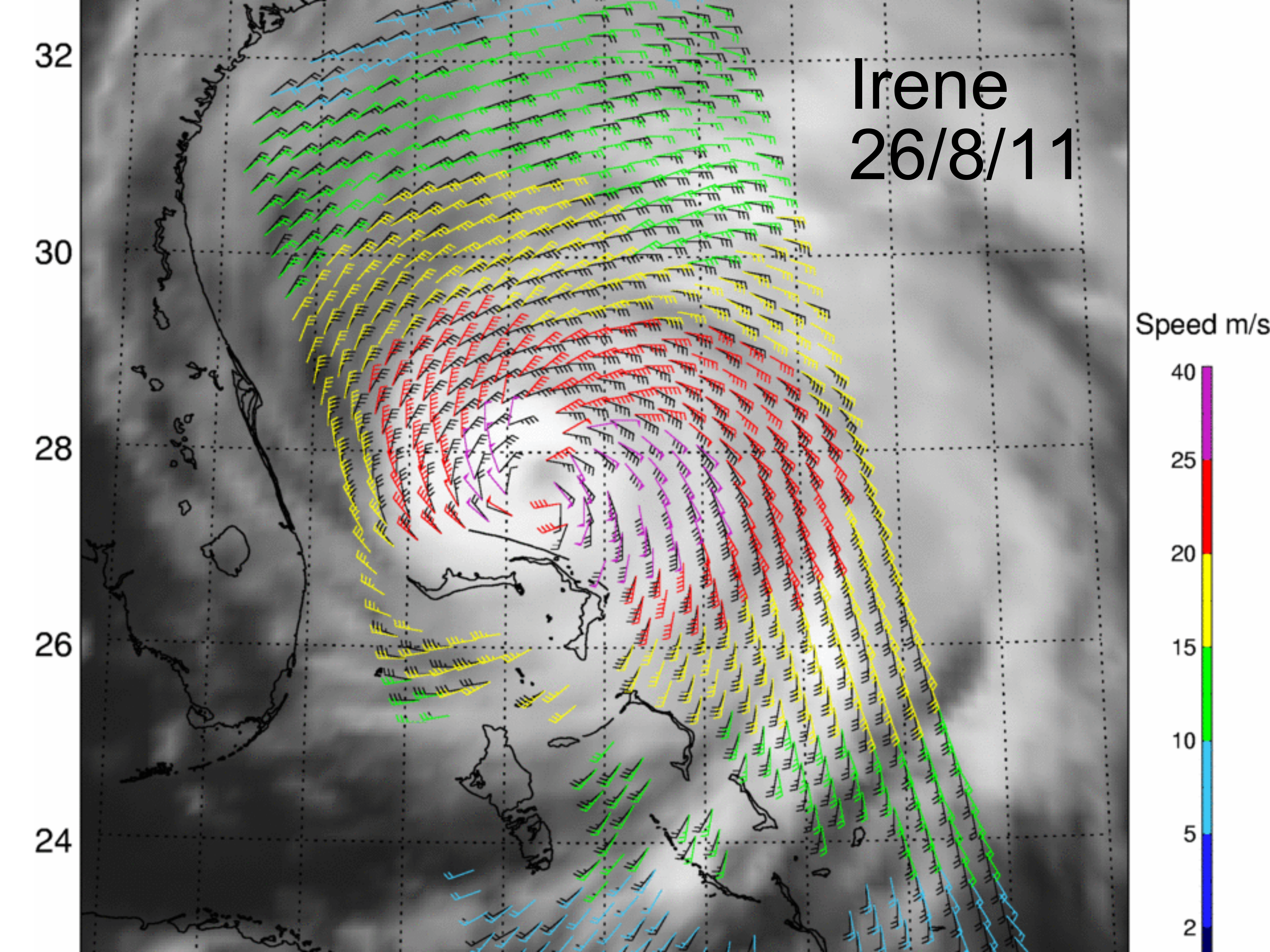
Recommendation of old satellite observations for assimilation:

- HIRS on Nimbus-6 (mid 70s)
- PMR on Nimbus-6 (pre SSU mid 70s)
- SSM/T/T-2 (pre AMSU-A/B) 1994-1999
- *SMMR (pre SSM/I) 1978-1987 + SSMIS(2005-present)*
- *SCAMS (pre MSU) 1975-1976*
- AVHRR polar AMVs (1978-present)
- NSCAT scatterometer (1996-1997)
- BUV and SBUV on NIMBUS-4/7 ozone (1970-1988)

Reprocessed or new forward model

- Reprocessed AMSU/MHS (1999-present)
- Reprocessed AMVs (Meteosat, GMS, GOES)


GCOS ECV
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
Atmospheric
Surface precip
Surface wind
TOA radn budget
Solar irradiance
Temp profile
Water vapour profile
Wind profile
Cloud properties
Carbon dioxide
Methane
Ozone
Other GHG
Aerosols
Oceanic
SST
Surface salinity
Sea level
Sea state
Sea-ice
Currents
Ocean colour
Terrestrial
LST
Lake levels
Snow cover
Glaciers and ice caps
Permafrost
Albedo
Land cover (inc veg)
fAPAR
LAI
Biomass
Fire
Soil moisture
Looking to the future….
Some variables in danger of being lost or degraded!
Key
Good capability
Some capability but needs improve
Poor capability
Capability lost
Capability reduced
No capability
Assumes fly microwave imager



Irene
26/8/11
32
30
28
26
24
Speed m/s
40
25
20
15
10
5
2

Impact of Scatterometers in the Met Office

Trial compared with NO-SCAT control	Score against observations (+/- 0.05)
ALLSCAT	+0.97
ASCAT only	+0.61
QuikSCAT only	+0.66

- The table shows that ASCAT gives approximately the same impact as QuikSCAT on Met Office forecasts - from the **June 2007** assimilation trial
- It is also clear that "Two global coverage scatterometer missions provide significantly greater benefit to the numerical weather prediction community than a single mission can deliver alone."

- Met R&D Technical Report 511, Met Office, March 2008.

Summary

- Satellite data archaeological studies have shown a number of promising datasets worth investigating
- Problems are:
  - Finding dataset on readable medium
  - Finding Metadata (e.g. spectral responses, polarisation,…)
  - Assessing if biases are stable enough and noise is low enough
- A number of reprocessed datasets available now to replace existing ones (AMVs, radiances, ..)
- There is scope to improve the assignment of observation errors in reanalyses
- Need to ensure future continuity of satellite datasets

If you have any information please contact me.

roger.saunders@metoffice.gov.uk

Any questions?