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TAKING THE PULSE OF OUR PLANET FROM SPACE

# Satellite data rescue from Earth observing missions of the 1960s and 1970s

**T. W. Hall**[1], *J. P. D. Mittaz*[1], *A. Klonecki*[2], *C. J. Merchant*[1,3]
[1] University of Reading, UK
[2] SPASCIA, Toulouse, France
[3] National Centre for Earth Observation, UK

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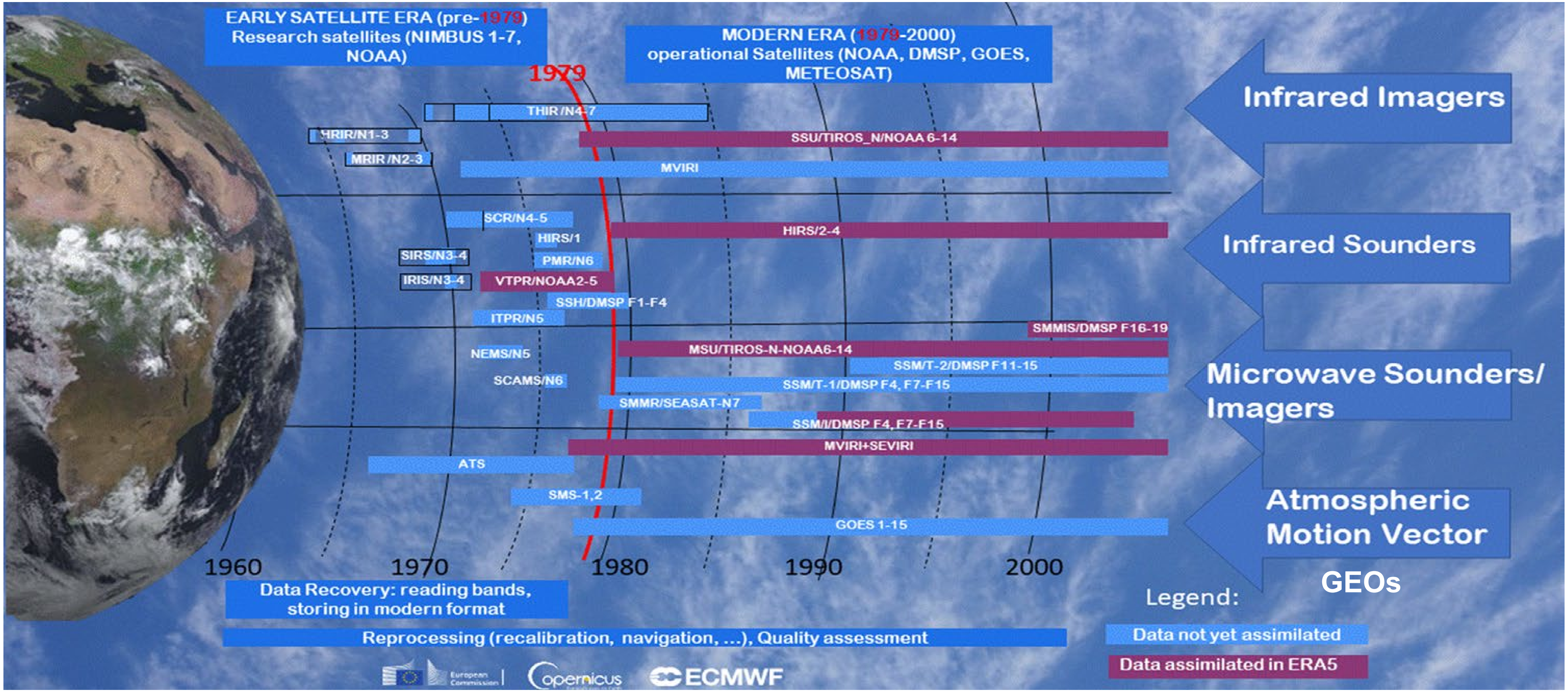
# Motivation

- Satellite radiances form a critical component of the observing system in numerical weather prediction (NWP), but very little satellite data is assimilated before 1979

- This is despite there being a number of satellite missions dating back to 1964 with potentially valuable data to help constrain past climate (through assimilation in the next generation of climate reanalyses)

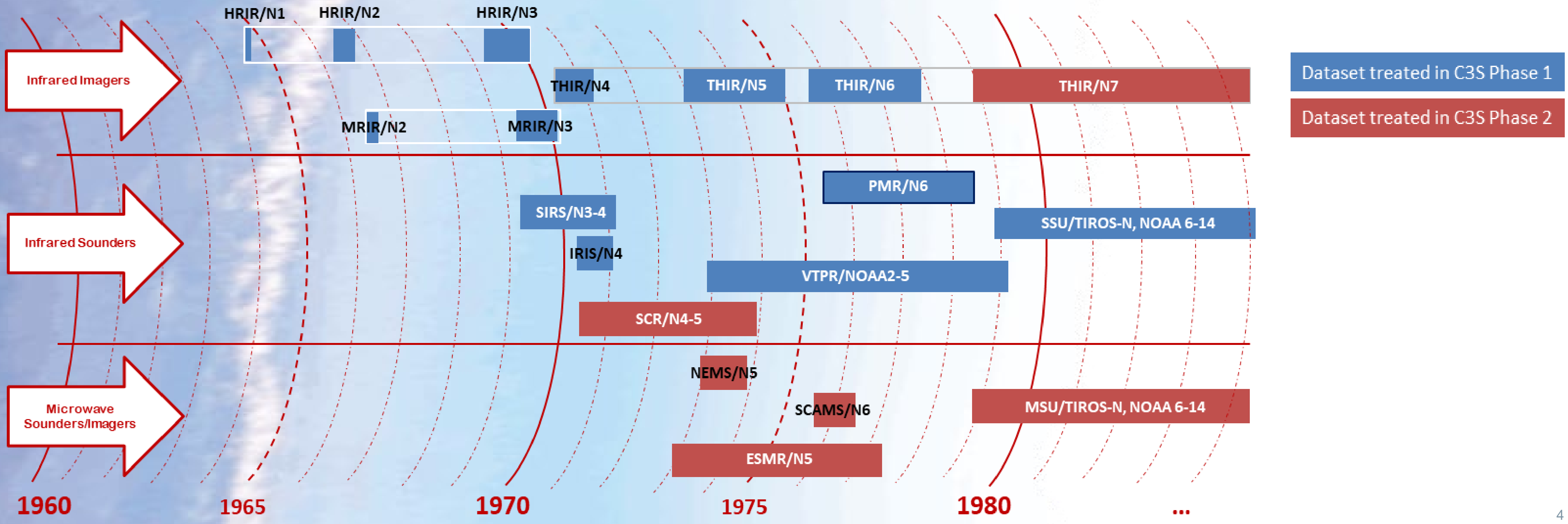
# Satellite data rescue in C3S

*Satellite data rescue & reprocessing activities in C3S*



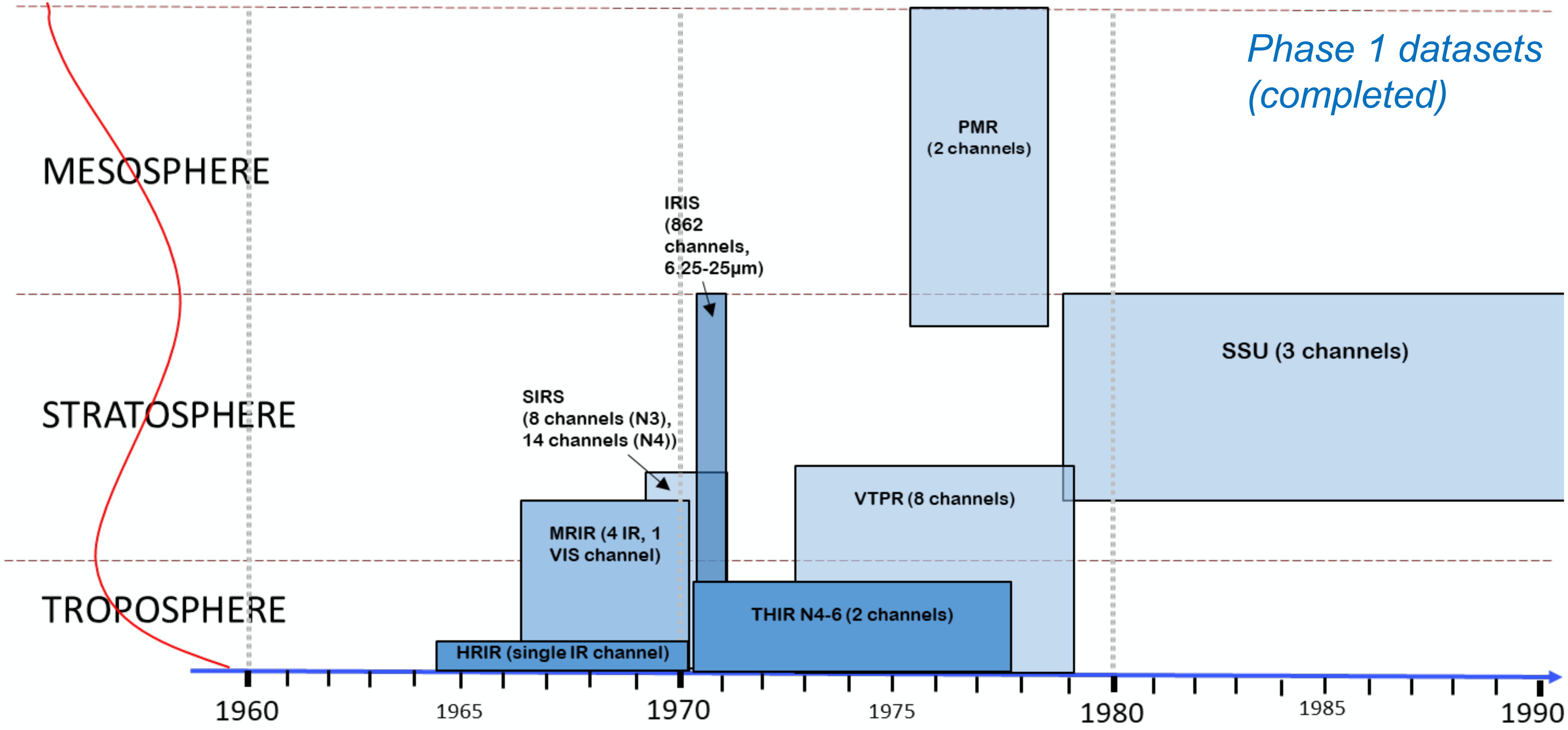
# Early satellite data rescue

- Our work focuses on the recovery, assessment and preparation of a selection of these pre-1979 satellite data records for assimilation in ERA6
  - **Completed** (C3S 311c_Lot1): 2018-2021 (**blue** sensors)
  - **In progress** (C3S2 314): 2022-2024 (**red** sensors)



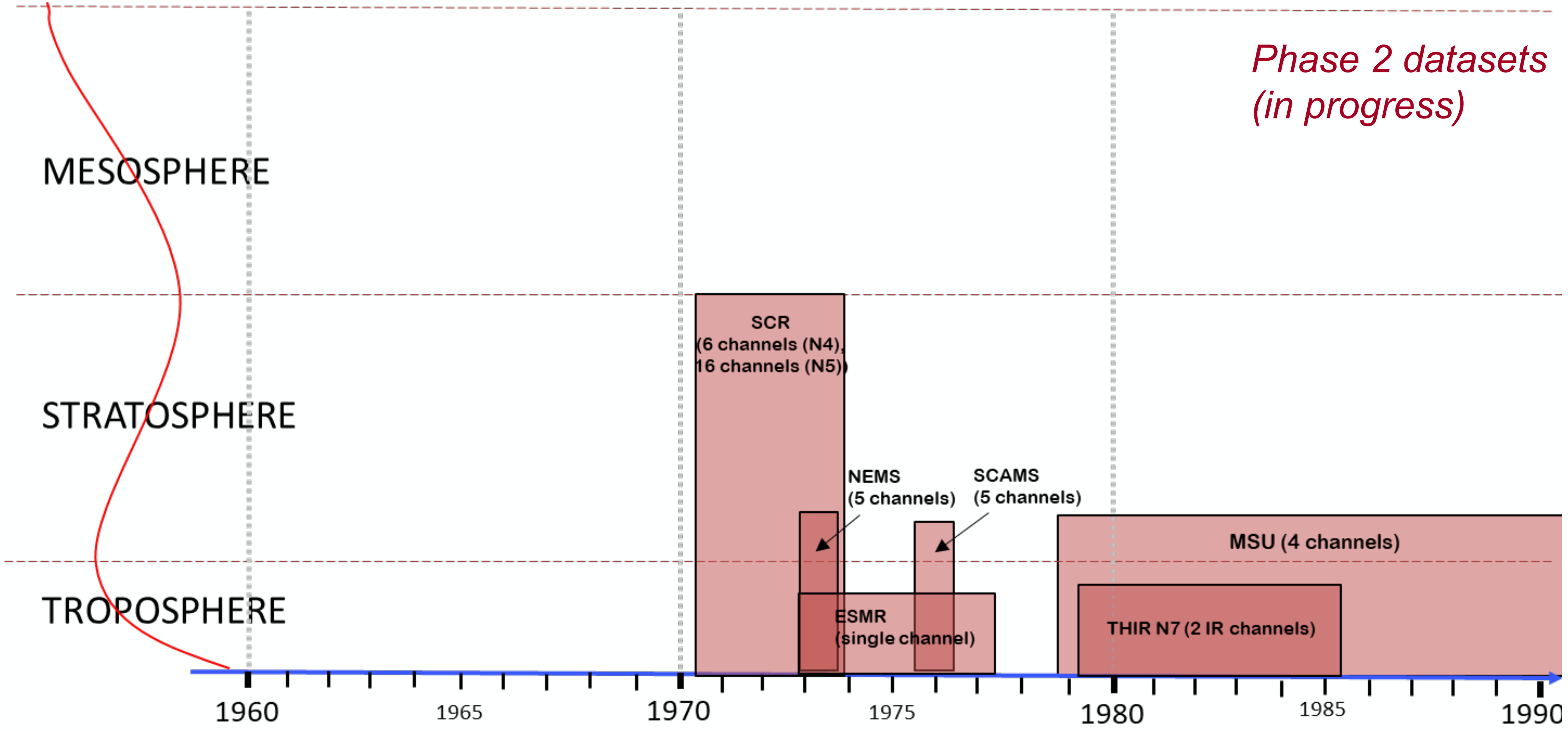
# Sensor vertical sensitivity

- Transition from surface-only sensing in 1964 (HRIR) to stratospheric sounding starting in 1969 (SIRS)
- IRIS was the first hyperspectral sounder (10 months data in 1970-71)

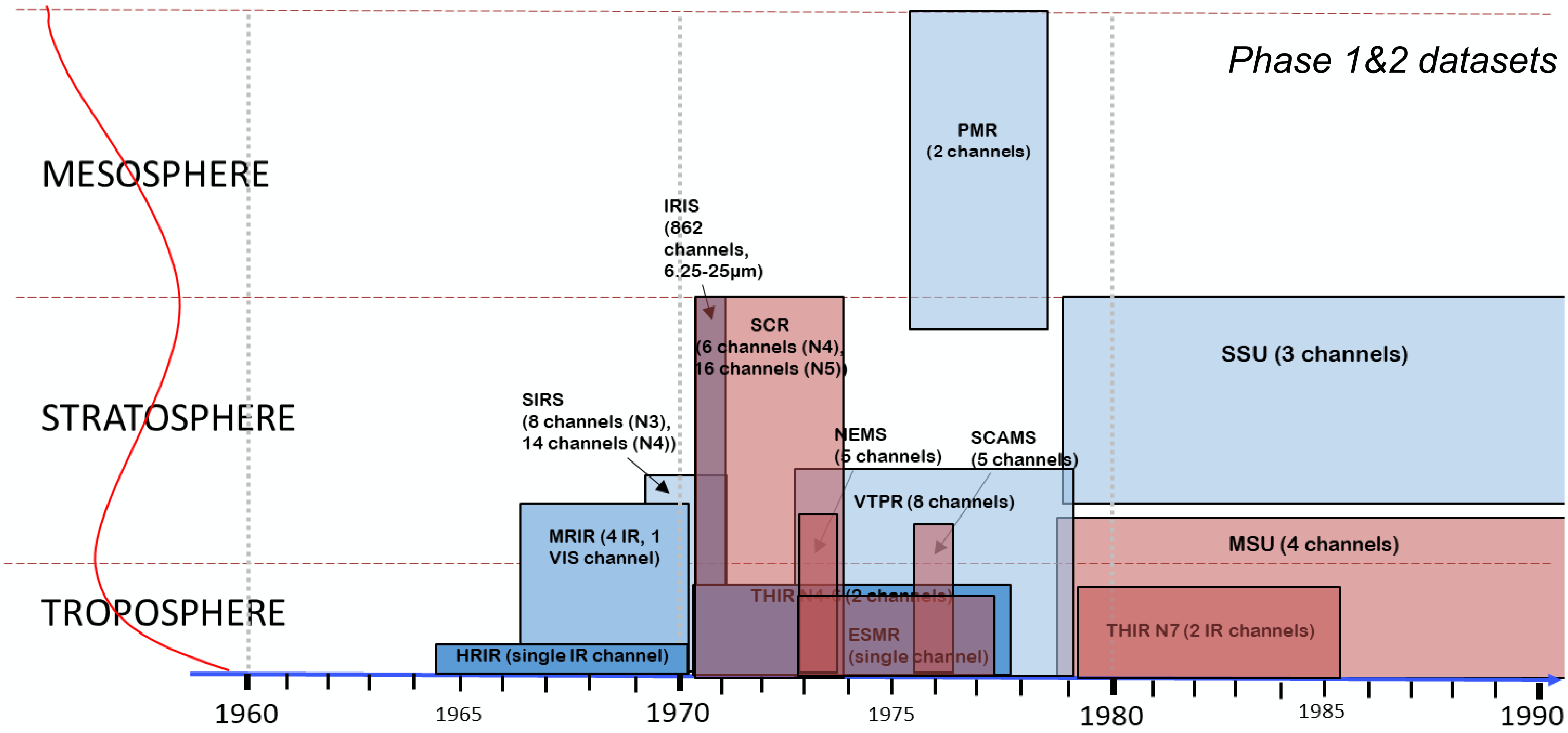


# Sensor vertical sensitivity

- The SCR was a stratospheric sounder with 6 channels in the 15 µm $CO_2$ band
- NEMS, SCAMS and MSU were microwave sounders (surface → lower stratosphere)



# Sensor vertical sensitivity

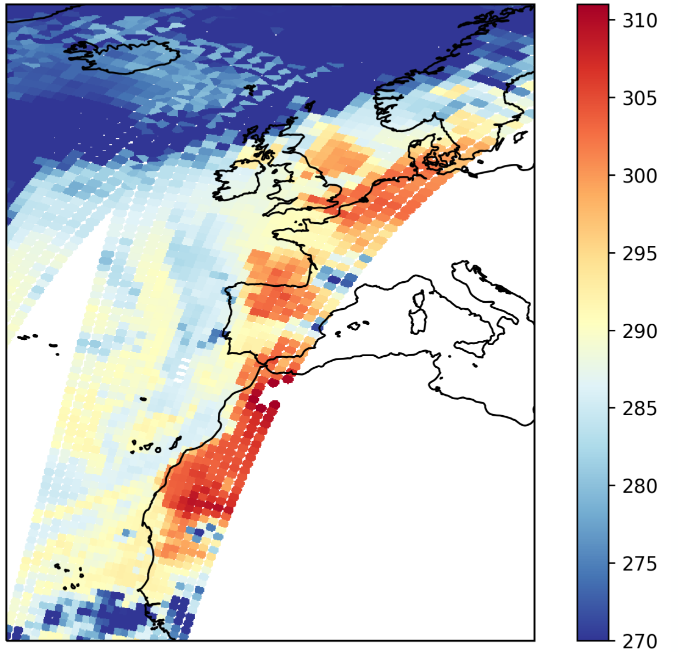


# Data quality issues

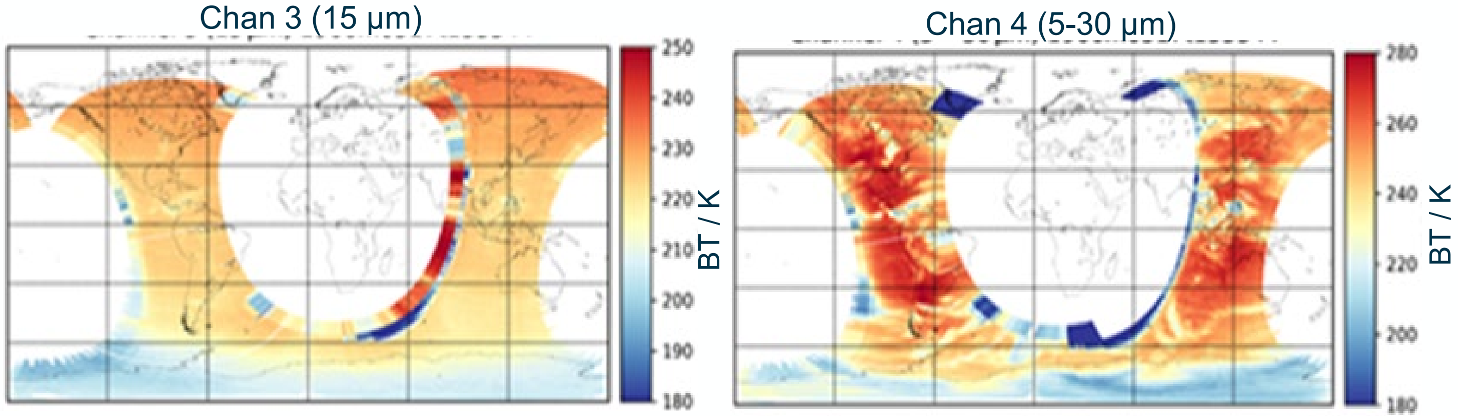
- Significant amounts of bad data are present in the original datasets for most sensors

  e.g. corrupted/noisy data, calibration issues, timing/geolocation errors…

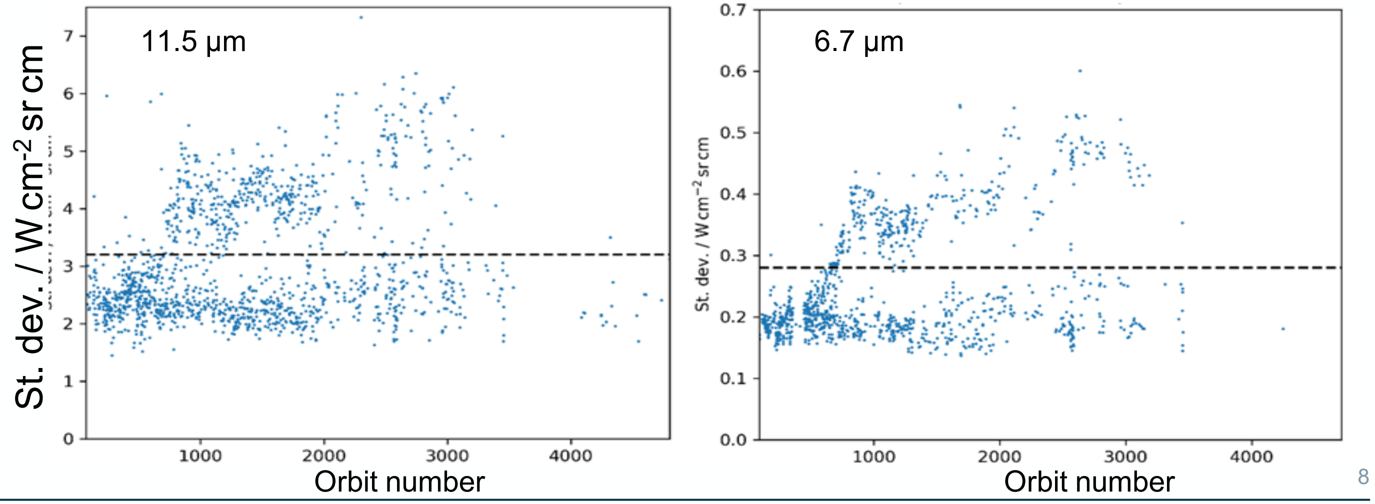
*VTPR geolocation errors (27/06/76)*




*Nimbus 2 MRIR: contaminated data at swath edges*

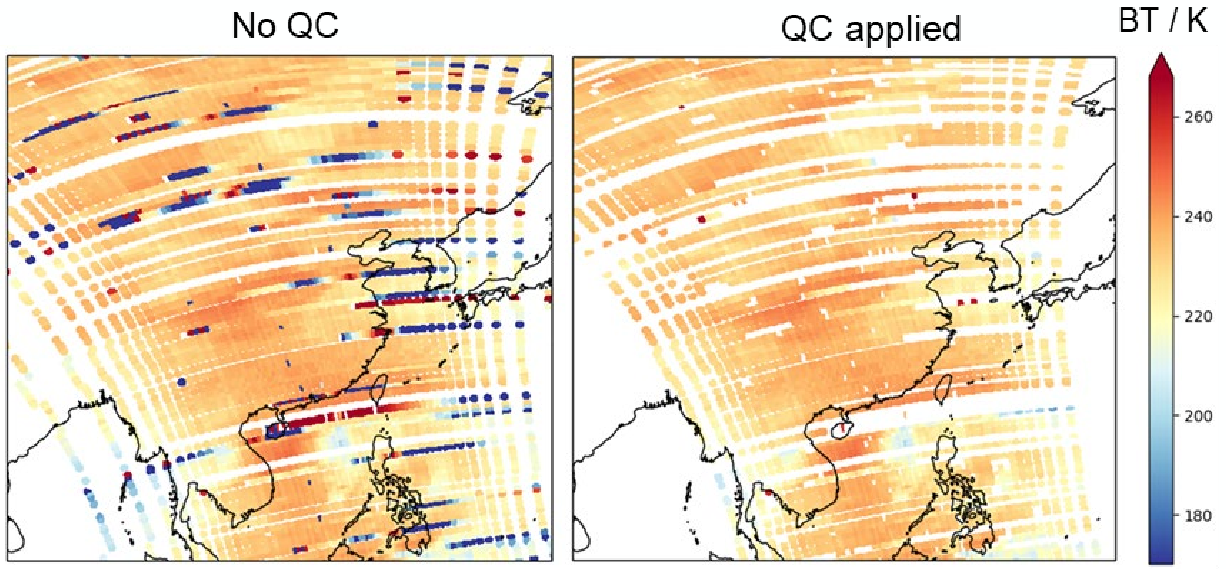



*Nimbus 4 THIR: elevated noise due to tape recorder flutter*

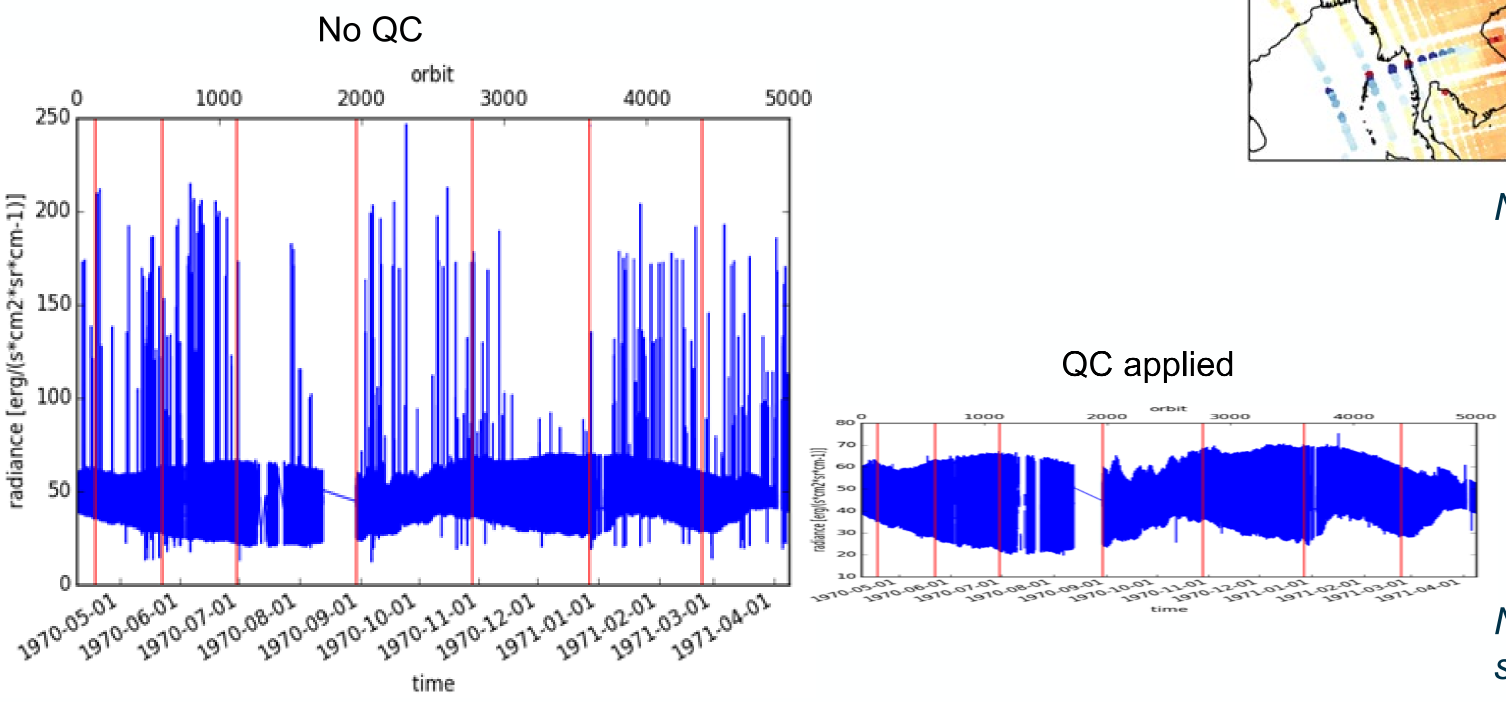


# Data QA: Flagging

- Additional quality flags have been developed to greatly improve overall data quality and usability
- These flags are encapsulated by an overall quality flag for ease of use




*Nimbus 2 MRIR 6.5 µm channel (28/05/1966)*




*Nimbus 4 SIRS-B Channel 7 spike removal*

# Data QA: Geolocation updates

- We have used modern software to recalculate the geolocation for each sensor, with significant improvements for most sensors

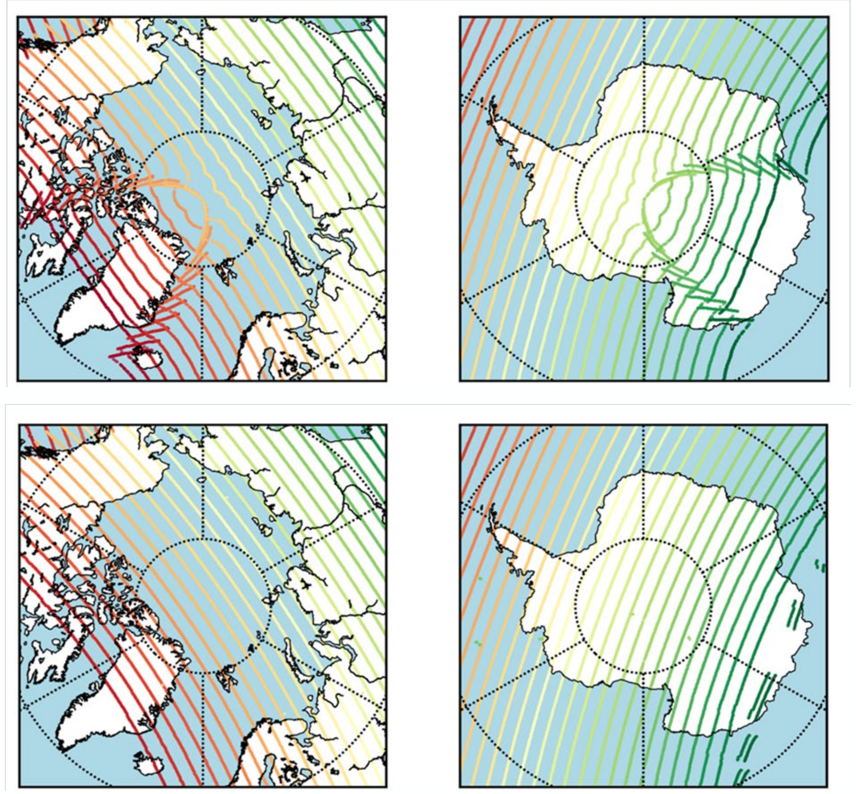
Times, sensor geometry, TLEs → Pyorbital → Pixel locations, satellite angles, altitude

- Data that would be unusable can be recovered in some cases
  - Correction of IRIS orbit tracks in January 1971
  - Clear improvements at the poles for all Nimbus sensors

*Nimbus 4 anchor point trajectories over the poles:*

Original

Corrected



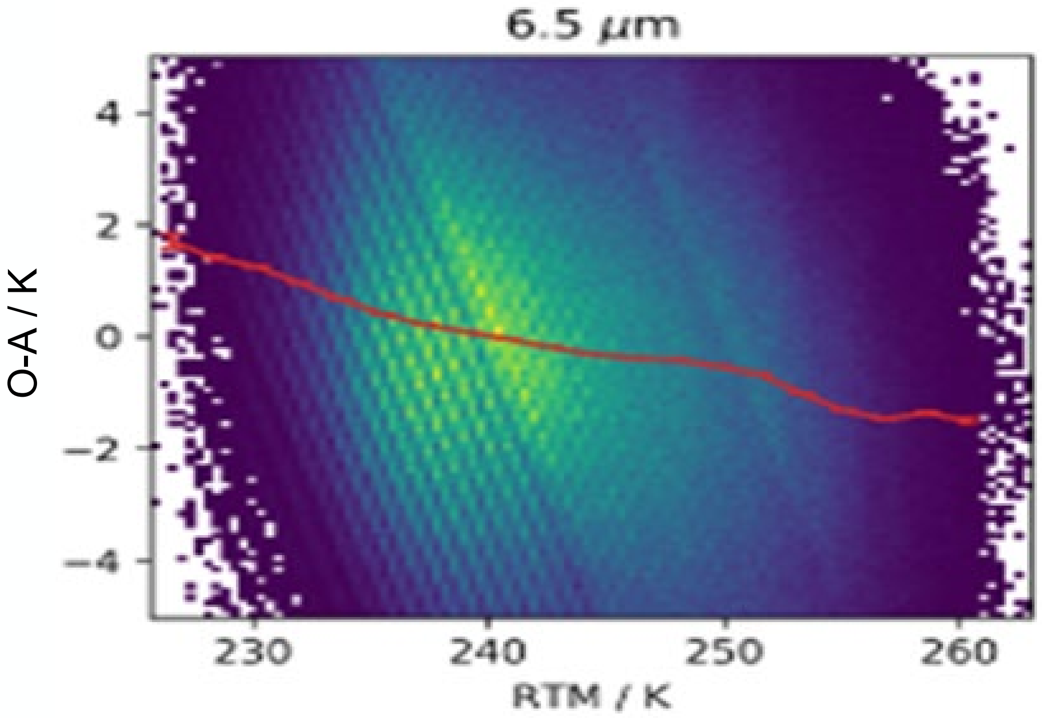
# Comparison to RTM simulations (O-A)

- For further QA and to characterise potential instrument biases in preparation for assimilation in ERA6, we have assessed the radiances against RTM simulations with the background state from ERA5 (O-A)
  - Restricted to clear-sky conditions for surface and tropospheric channels

- We have looked for tendencies in O-A as a function of parameters such as scene temperature, latitude, viewing angle, and instrument temperature

- Interpretation of these tendencies can be complex…
  - E.g. scene temperature dependent trends may be due to calibration-related errors, spectral response function errors or model biases

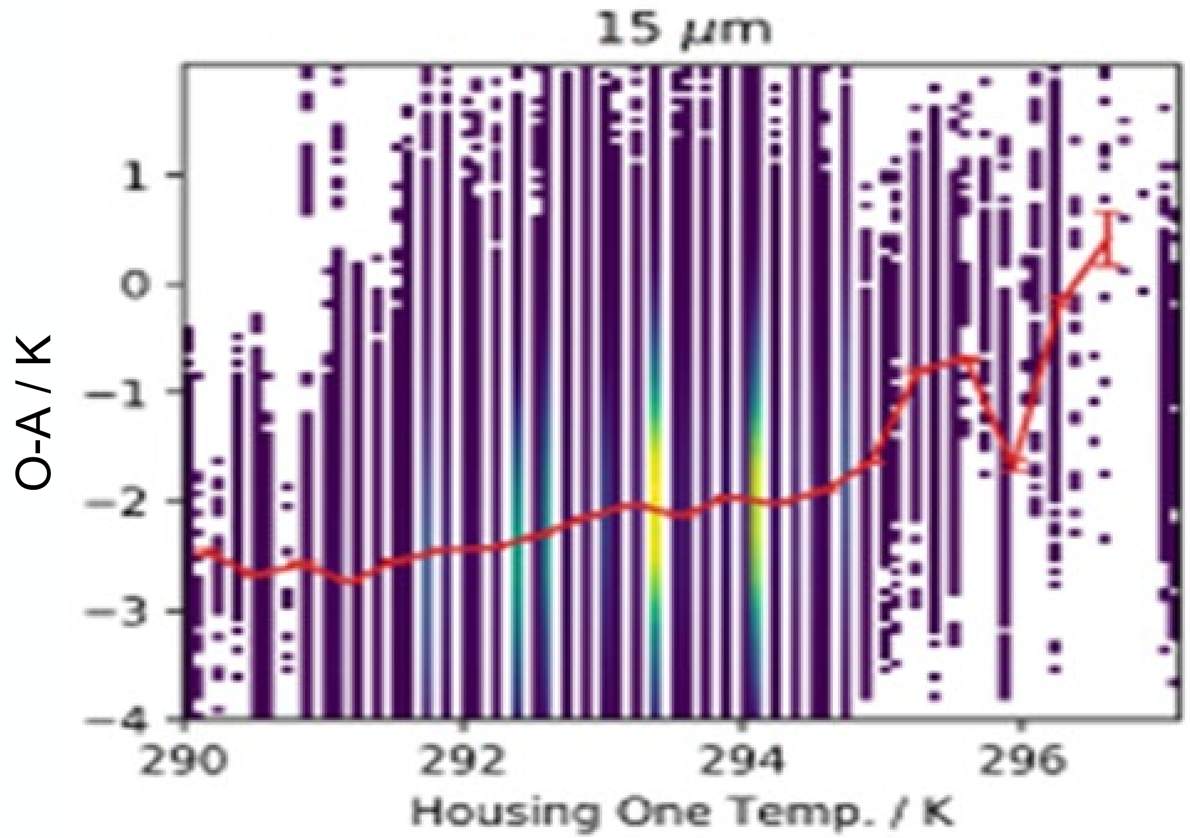
*Nimbus 2 MRIR O-A vs scene temperature (RTM)*



# O-A: instrument error

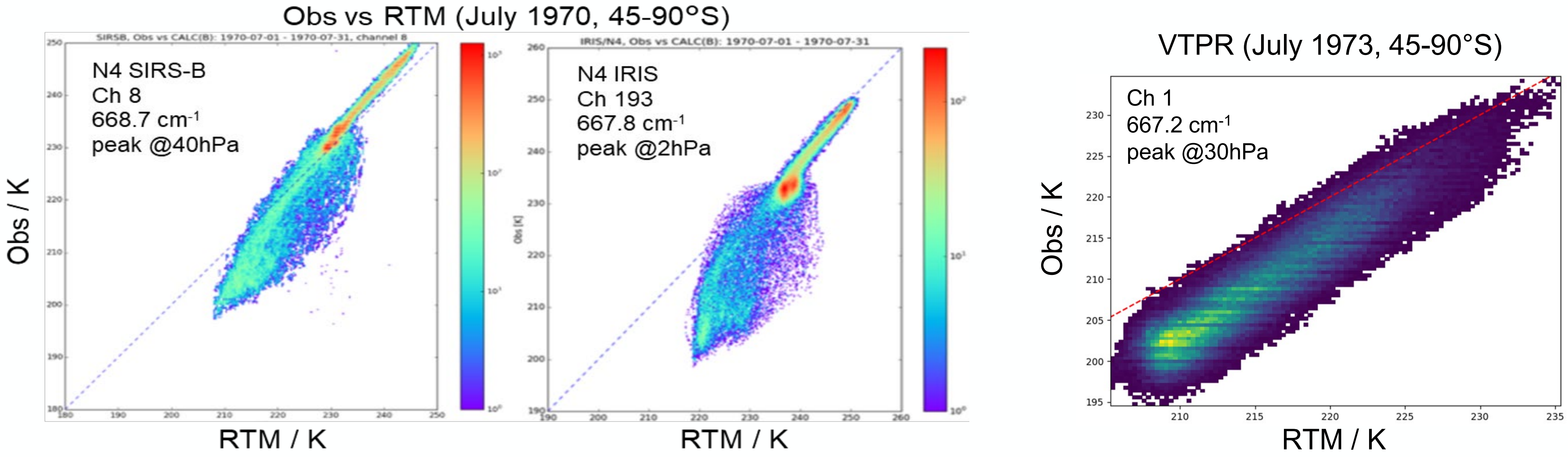
- Example of likely **instrument error**:
    - Trends seen in O-A as a function of instrument (housing) temperature are evidence of error in the original instrument calibration as the housing was used as a calibration reference

*Nimbus 2 MRIR clear-sky O-A vs housing temperature*



# O-A: model stratospheric warm bias

- Example of likely **model error**:
  - A persistent negative O-A bias (model warm bias) is seen for IRIS & SIRS-A & SIRS-B (1969-1971) for channels peaking in the mid/upper stratosphere at high southern latitudes in local winter
    - Departures of 10-20K for the coldest scenes over the South Pole




- The hypothesis of model error is supported by available rocketsonde T profiles over Antarctica (not assimilated in ERA5) which indicate large differences with ERA5 in 1971-1972, but much smaller differences from 1973, possibly due to assimilation of VTPR data…
- VTPR data also indicate a bias relative to ERA5 over the South Pole, but the differences are much smaller than for SIRS and IRIS

# Summary

- A number of early satellite missions during the 1960s and 1970s generated significant amounts of Earth observing data, the majority of which is not currently exploited in climate reanalysis
- As part of the wider C3S data rescue activities we have worked on preparing the data from a selection of these early sensors for assimilation in ERA6
    - These sensors have a diverse range of sensing capabilities with vertical coverage from the surface up to the mesosphere
- Much of this early data suffer from a range of quality issues - extensive efforts have been made to improve data quality and usability through quality flagging and corrections to the instrument geolocation
- Through O-A assessment we can better understand instrument behaviour and characterise biases
- Discovery of an apparent stratospheric warm bias in ERA5 highlights the potential value of assimilating data from these historic satellite missions

# Sensor characteristics

## Phase 1

| Sensor | Time period | Channels | Function |
|---|---|---|---|
| HRIR | 1964-1970 | Single 3.4-4.2 µm channel (Nimbus 1&2) and additional 0.7-1.3 µm component (Nimbus 3) | Map night-time cloud clover and surface/cloud top temperature |
| MRIR | 1966-1970 | 6.7 µm water vapour, 10.5 µm window, 15 µm $CO_2$, 5-30 µm, 0.2-4.0 µm visible | Detect surface up to lower stratosphere temperature, water vapour, reflected solar energy |
| SIRS | 1969-1971 | 7 channels in $CO_2$ band and 1 window channel (Nimbus 3) and extra 6 channels in water vapour band (19-35 µm) on Nimbus 4 | Atmospheric sounding up to mid-stratosphere (220km footprint) |
| IRIS | 1970-1971 | 862 channels in 400-1600 $cm^{-1}$ (6.25-25 µm) interval | Early hyperspectral sounder with surface sensing capability |
| THIR (N4-N6) | 1970-1977 | 6.7 µm water vapour and 11.5 µm window | Map cloud cover, cloud top temperature, surface temperature, relative humidity |
| VTPR | 1972-1979 | 8 channels in window, $CO_2$ and water vapour bands (11.9-18.7 µm) | Atmospheric sounding up to mid-stratosphere |
| PMR | 1975-1978 | 2 channels (cells) in 15 µm $CO_2$ band | Uses pressure modulation to sense at different heights in upper stratosphere and mesosphere (45-90 km) |
| SSU | 1978-2006 | 3 channels (cells) in 15 µm $CO_2$ band | Retrieval of temperature in mid/upper stratosphere (29-44 km) |

## Phase 2

| Sensor | Time period | Channels | Function |
|---|---|---|---|
| THIR (N7) | 1978-1985 | 6.7 µm water vapour and 11.5 µm window | Map cloud cover, cloud top temperature, surface temperature, relative humidity |
| SCR | 1970-1973 | 6 channels in the 15 µm $CO_2$ band | Atmospheric temperature sounding up to upper stratosphere |
| NEMS | 1972-1973 | 5 channels (22.235, 31.4, 53.65, 54.9, 58.8 GHz) | Atmospheric sounding up to lower stratosphere (nadir only) |
| SCAMS | 1975-1976 | 5 channels (22.231, 31.65, 52.863, 53.845, 55.445 GHz) | Atmospheric sounding up to lower stratosphere (across-track) |
| ESMR | 1972-1977 | Single channel at 19.35 GHz | Sea-ice, land composition and rainfall over ocean |
| MSU | 1978-2005 | 4 channels (50.30, 53.74, 54.96, 57.95 GHz) | Temperature sounding up to lower stratosphere |

# Characterising uncertainties

- Uncertainty trees can be used as a tool to identify all possible sources of error contributing to the measured radiance
- We can estimate instrument noise and digitisation but difficult to quantify other error sources…