Modelling observation errors for historical datasets

Climate Change

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ECMWF & C3S for ERA-Interim & ERA5 data
NWP-SAF for RTTOV & RADSIM

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Outline

- Historical data records
- Revisiting historical observation errors (climate reanalysis)
- On the importance of references: bias terminology & a simulation
- Better understanding of uncertainties in reprocessed data records
- Conclusions

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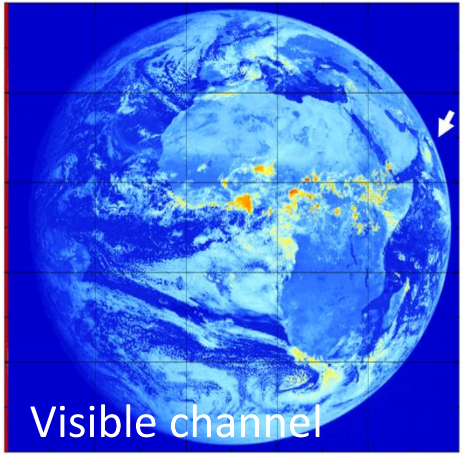
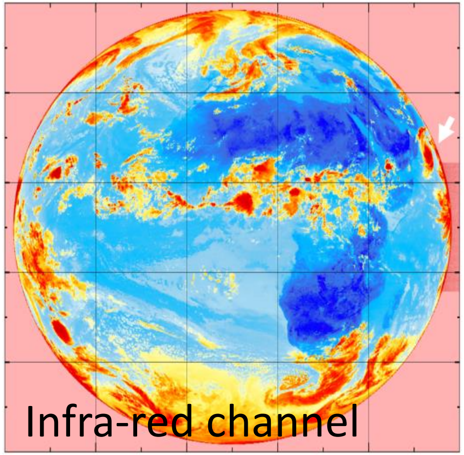
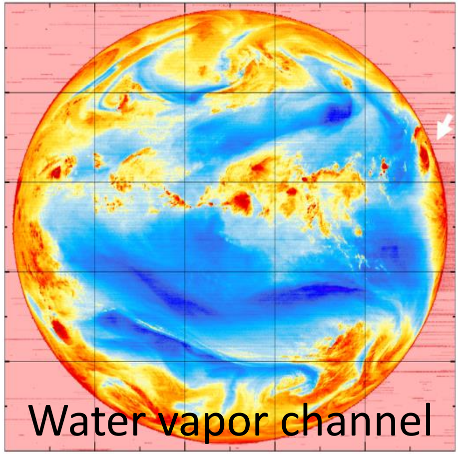
Meteosat-1 (launched in 1977)

22 Sep 1979 09:30







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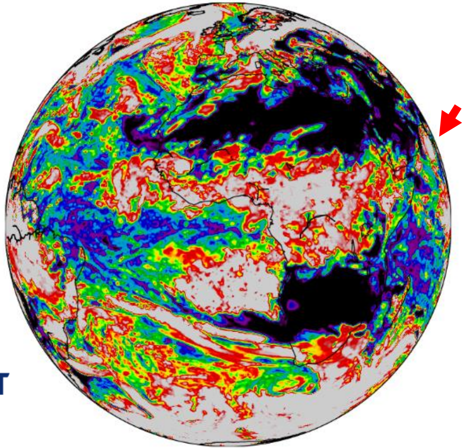
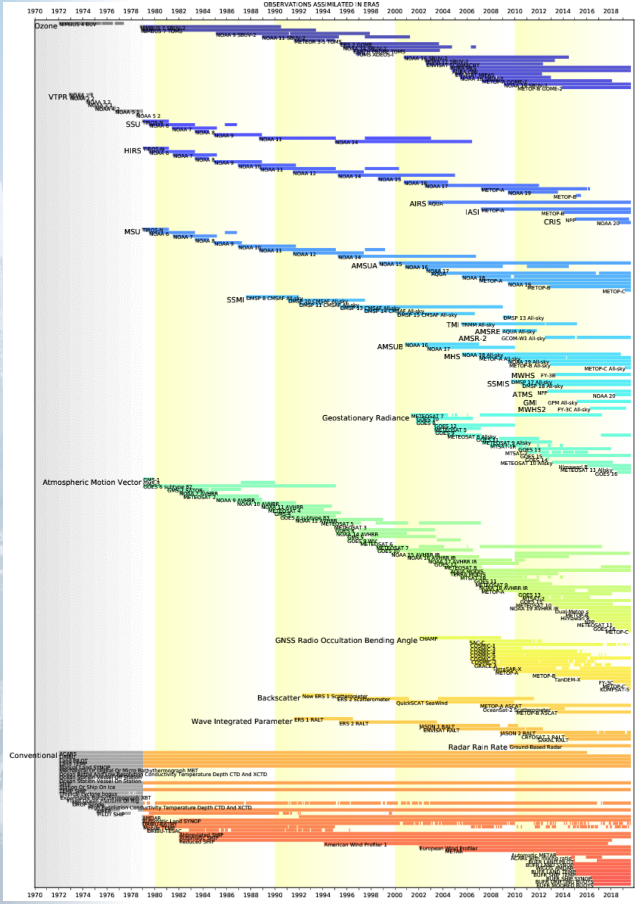


ERA5 Total Cloud Cover

Historical data records



Satellite observations in reanalyses span a half-century

➔ Additional satellite data records exist, though not in "ready-form" for assimilation (reprocessing required).

➔ Historical data records pose specific challenges:

Todays' **instruments**:

- improve design upon legacy instruments,
- generally well-characterized before launch, (and sometimes even after, *cf.* NPP, METOP manoeuvers),
- include in-flight calibration systems

Today's **data**:

- processing generally well-documented,
- often inter-compared *(cf.* ***GSICS talk by T. Hewison****),*
- contextually well-described (other satellites),
- supported by simul. models developed since mission onset

Today's **metadata**:

- central system: WMO Oscar/Space

Data & methods used in this talk

Observations, and **models**!

+ At the intersection: **Data assimilation observation feedback**

- From 2 reanalyses (*cf.* ***talk by B. Bell***), using ECMWF ODB-API to decode the data
  - ERA-Interim (1979-2019)
  - ERA5 (1972-2019), ERA5.1 for years 2000-2006
- Contains:
  - Observation departures from background and from analysis
  - Data assimilation flags
  - Bias estimates, for bias-corrected observations
  - Observation random error assumed by the assimilation (sigo)
  - Background (random) error assumed by the assimilation (sigb)
- This is further complemented by computing Desroziers' diagnostics
  - Yields new estimates of sigo, sigb
- Drawing here examples from satellite data, in-situ data

<u>Reprocessed satellite data records</u>

- 'Observation data': HIRS and SSM/T-2 brightness temperature plus 'ancient' data: VTPR, MRIR, THIR…
- 'Model data': simulated brightness temperatures, based on ERA-Interim or ERA5, using 4D fields of temperature, humidity (+ ozone, CO_2 for HIRS), using RADSIM v2.2 and RTTOV v12.3

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Observation 'errors' in ERA5 (1)

- Consider here all radiance satellite obs. actively assimilated
- Compute, per instrument and per channel:
  - (estimated) systematic error = monthly average (biascorr) in ODB jargon
  - (assumed) random error = monthly average (obserror) in ODB jargon
    - Considering the monthly timescale smooths out short events, visible with occasional spikes in individual assimilation cycle results
  - Then consider the average over all months when the data are available
- For all distinct satellites/channels assimilated:
  - 1,172 entries
  - Group the various instrument channels for plotting, by technology (instrument type) and/or frequency band

Observation 'errors' in ERA5 (2)

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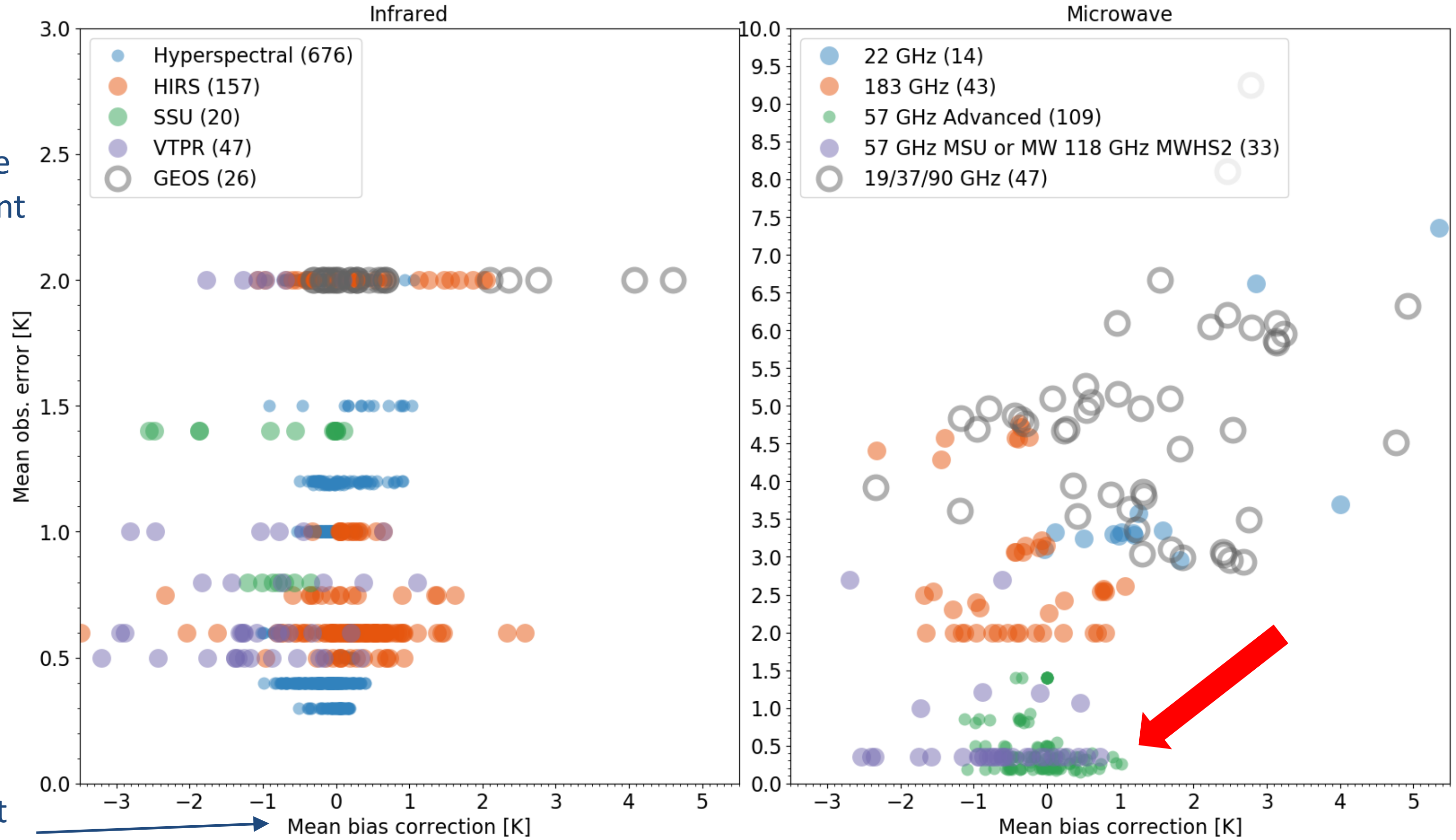
To characterize the 2nd moment ('random' component)

To characterize the 1st moment ('systematic' component)



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Brightness temperature observations assimilated in ERA5 (feedback 1972-2011); Diagnostics on a monthly basis, subjected then to average over all available months

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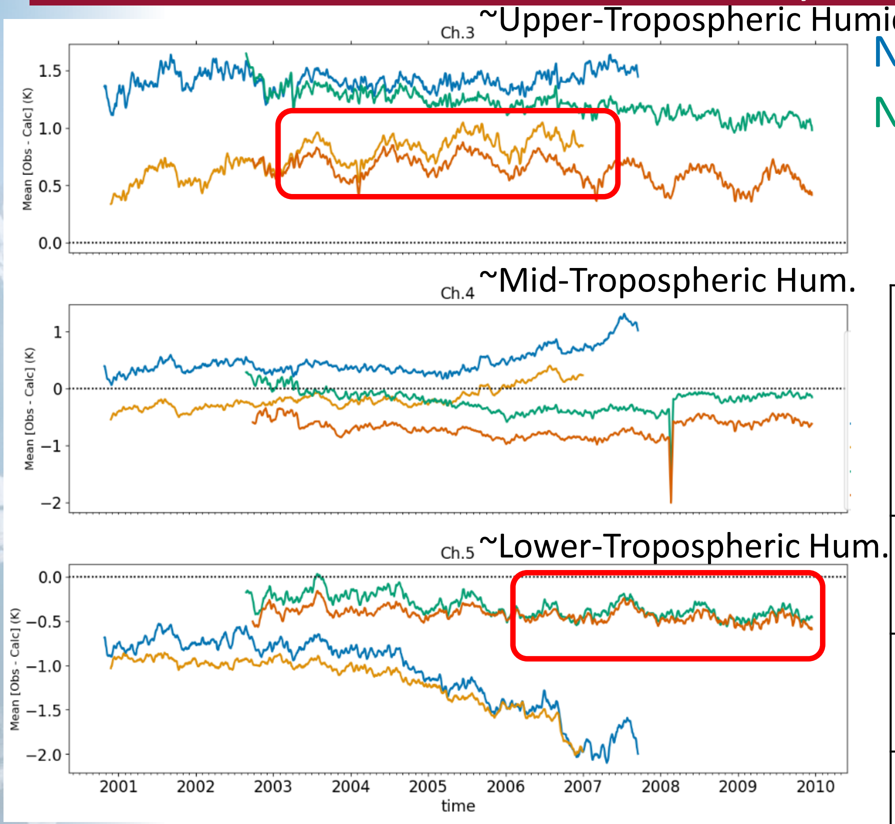
Time variations in systematic 'errors'



AMSU-B

NOAA-16, ERA-Interim

NOAA-17, ERA-Interim

NOAA-16, ERA5

NOAA-17, ERA5

Pearson correlation coefficient	NOAA-16 vs NOAA-17, for ERA-Interim	NOAA-16 vs NOAA-17, for ERA5	ERA5 vs ERA-Interim, for NOAA-16	ERA5 vs ERA-Interim, for NOAA-17
Channel 3 (183±1 GHz)	0.29	0.76	0.26	0.56
Channel 4 (183±3 GHz)	-0.44	-0.46	0.77	0.87
Channel 5 (183±7 GHz)	0.69	0.43	0.97	0.78

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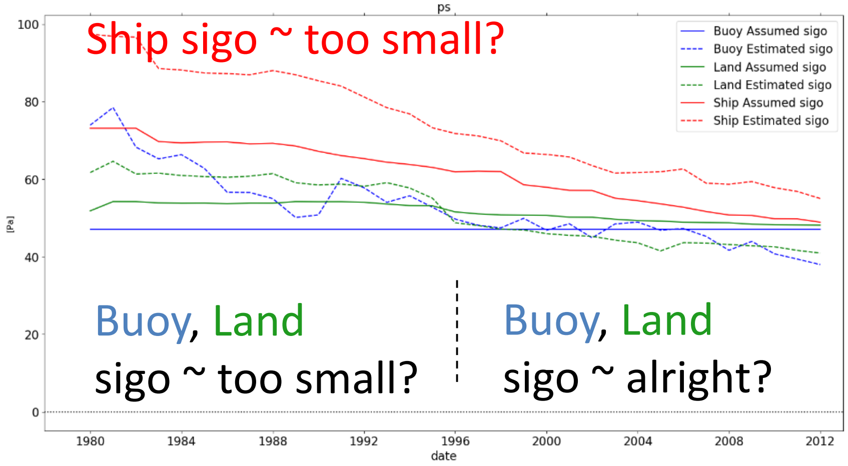
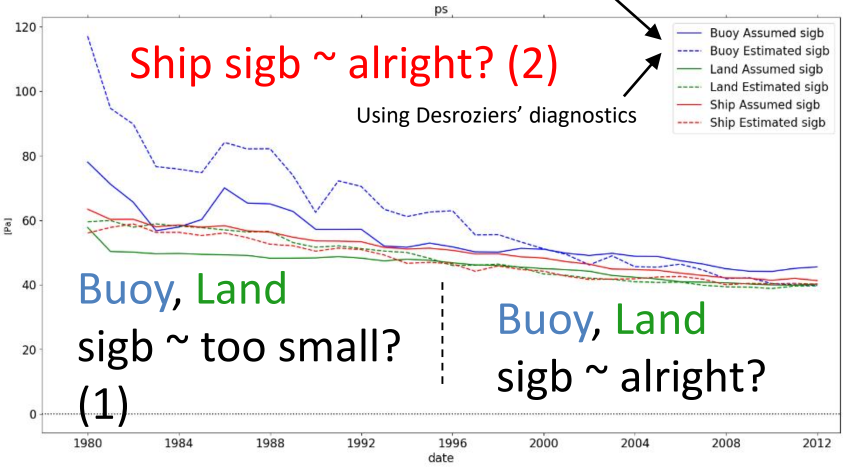
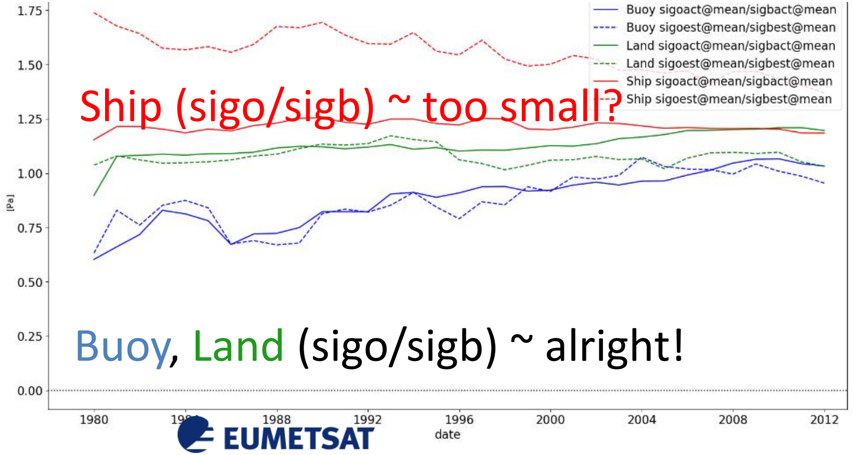
AMSU-B brightness temperature observations assimilated in ERA-Interim, ERA5 (feedback 1979-2011); Diagnostics on a daily basis, subjected then to 10-day moving average

Time variations in sigma_o (assumed)







➔ Difference between (1) and (2): greater regularity/stationarity of observations in (1) may lead to collapse the analysis ensemble spread for the next background

➔ Absence of time variation in sigma_o may be sub-optimal for reanalysis ***especially in poorly-observed areas and times*** (*cf.* CERA-20C, Laloyaux et al.)

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Surface pressure observations assimilated in ERA5 (feedback 1979-2011); All diagnostics, including Desroziers', estimated on a yearly basis; Results shown on 31 Dec. of each year

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Vocabulary

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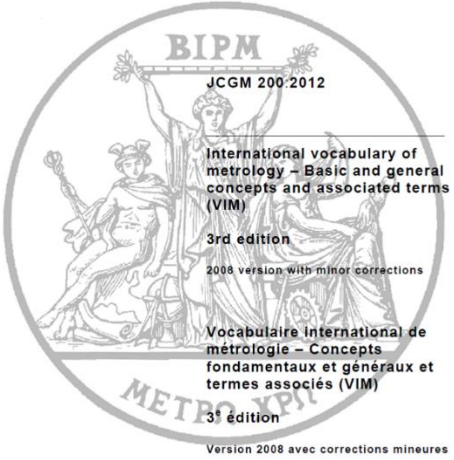
Bias: "our" term for the systematic component of the error

Rarely can we assert systematicity
… since we rarely have enough independent samples to assert the systematic nature, and we can generally not replicate the measurement in the same conditions

Rarely do we know exactly the error
… since we rarely know the true value, however we can measure distances between two estimates, or their projection(s)

International Vocabulary of Metrology (VIM guide) defines systematic error as

"component of measurement error that in replicate measurements remains constant or varies in a predictable manner"



The Bureau International des Poids et Mesures (BIPM):

- has the mission of establishing worldwide uniformity of measurements, traceable to the International System of Units (SI);
- is under the authority of the General Conference on Weights and Measures (CGPM), which has the authority for approving the definitions of the SI (first approved 1960).

Knowing what biases to expect… may help us better estimate them…

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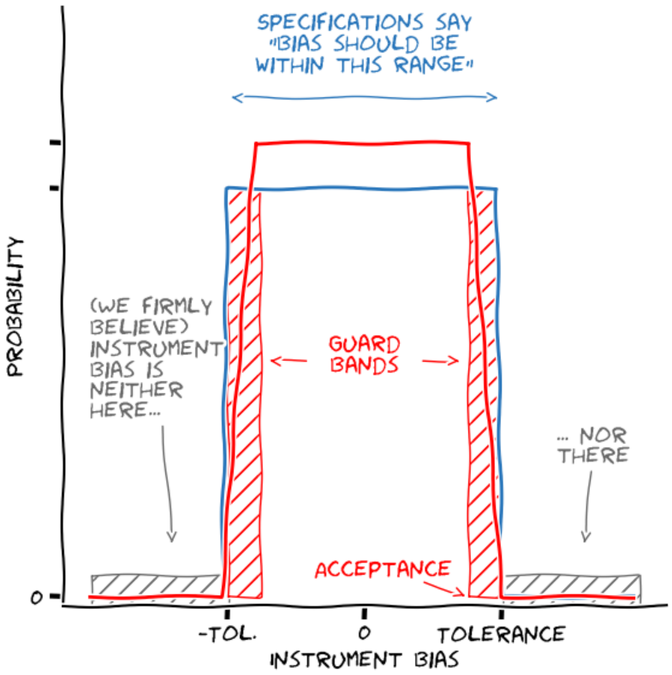
Instrument network simulation (1)

- Hypothetical population of 100,000 instruments
  - All calibrated with | systematic error | < *ε* (arbitrary unit)
    - Assuming a *uniform distribution* [- *ε*, + *ε*]
    - Considering also that acceptance occurs within a narrower band (because of verification uncertainty *u*)
  - 'Guaranteed' with | drift | < *D* (arb. unit, per year)
    - Assuming a *uniform distribution* [- *D*, + *D*]
  - Recommended calibration cycle:
    - Every *N* = (*ε* / *D*) years

- For this population of instruments, we investigate the distribution of biases:
  - Right after calibration, if one considers uncertainties in the calibration (and does not apply acceptance guard bands)
  - After *N* years, just before re-calibration
  - Mix of ages, recalibration every *N* years
  - Mix of specs. (e.g., different manufacturers): ε to 3ε, D to 3D
  - Mix of specs., mix of ages, delayed recalibration cycle
  - Mix of specs., mix of ages, mix of recalibration cycles



Methodology reference: Monte-Carlo method as described in the Joint Committee for Guides in Metrology (JCGM) 101:2008 Evaluation of measurement data — Supplement 1 to the "Guide to the expression of uncertainty in measurement" — Propagation of distributions using a Monte Carlo method, p. 15

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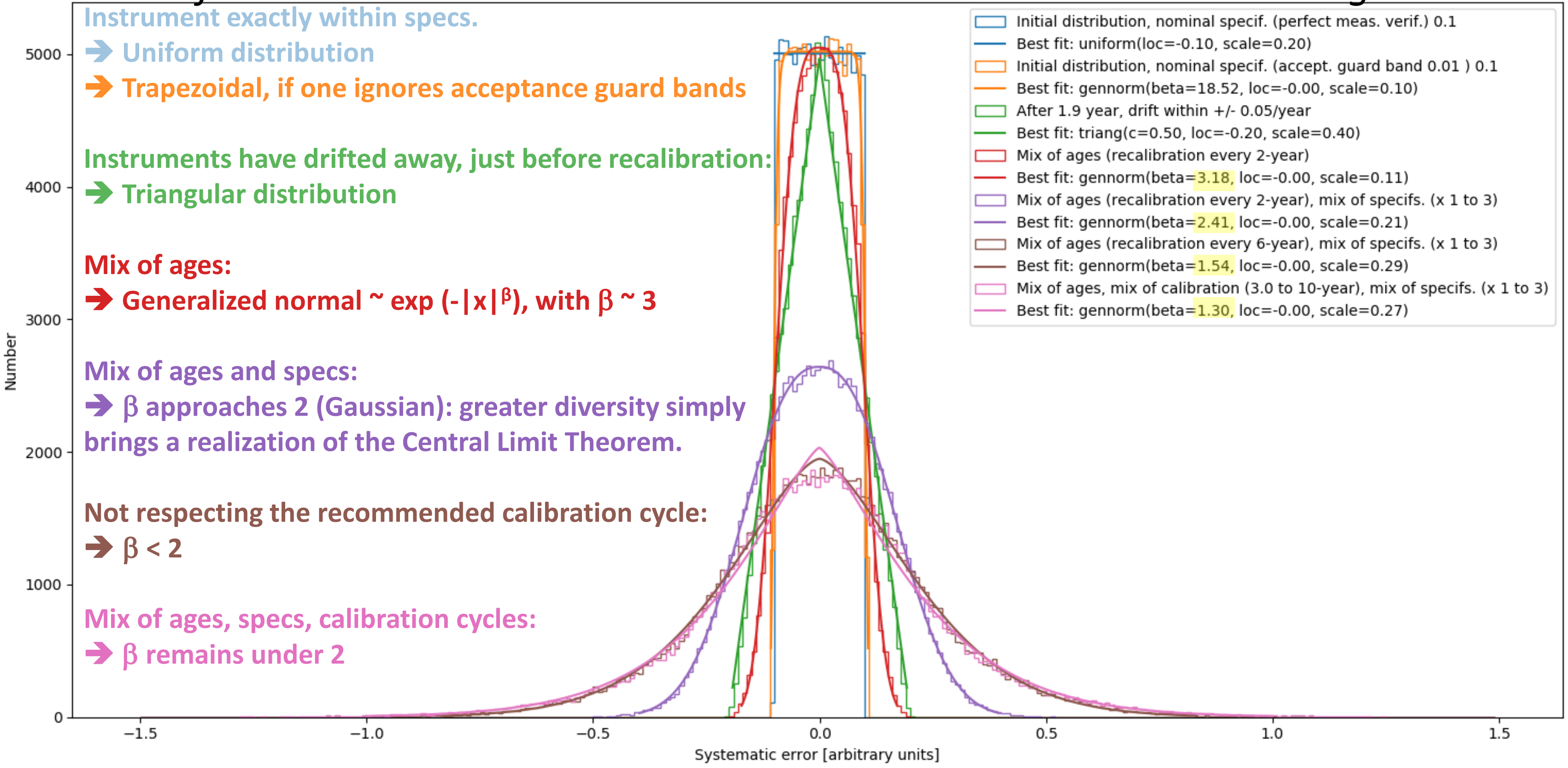
Instrument network simulation (2)

Best fit: Continuous line *Simulation results: histograms*



$\varepsilon = 0.1$ $u = 0.01$ $D = 0.05$ $N = 2$

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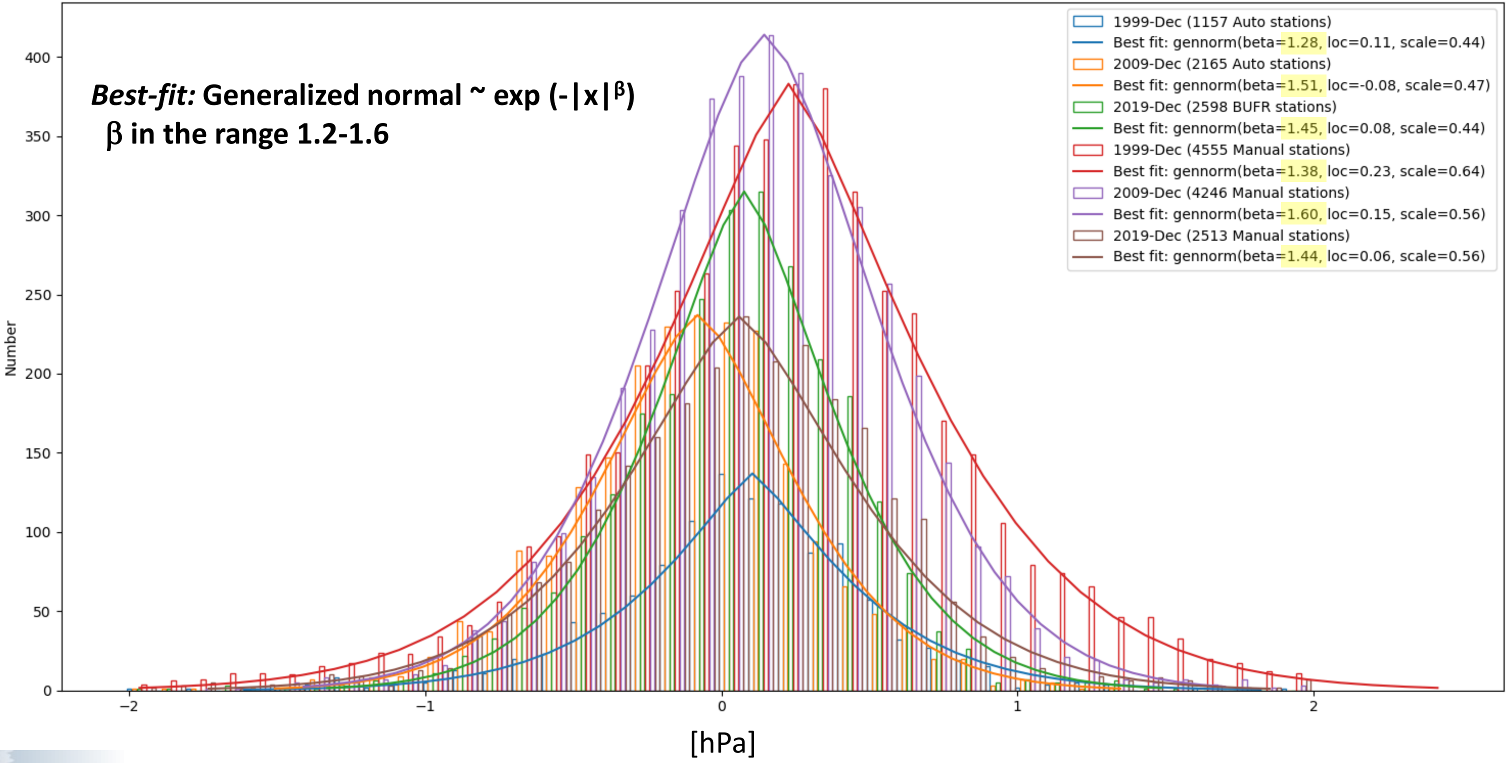
What about real data?

Biases in surface pressure estimated by ERA5, for land stations



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Surface pressure observations assimilated in ERA5; obs. feedback; monthly estimates for Dec. 1999, Dec. 2009, Dec. 2019

O u t l i n e

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Identifying quality issues

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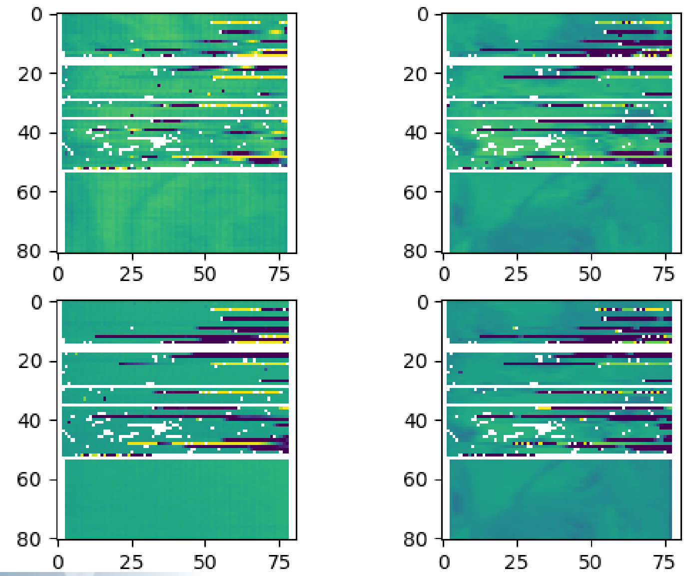
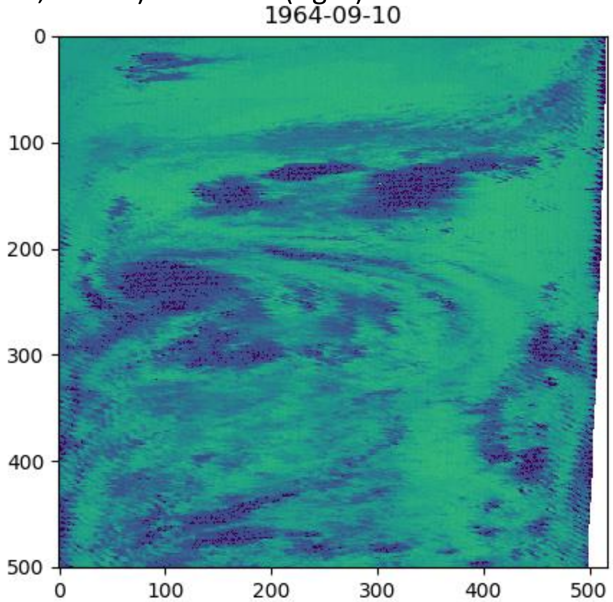
General aspects: Limited knowledge/documentation, Limited telemetry for most sensors, Significant amount of bad data, Can be quite noisy, Geolocation issues possible…

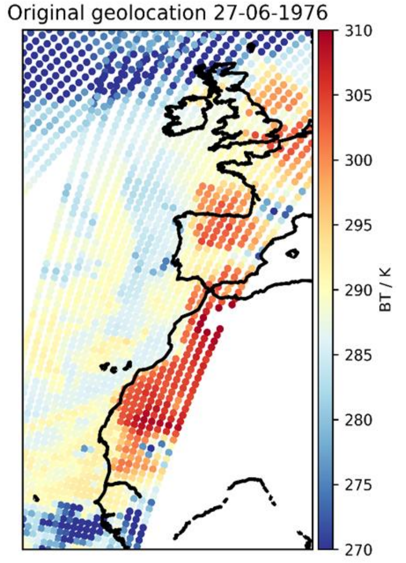
- ➔ Work ongoing to improve/categorize quality and uncertainty, and flag accordingly
- ➔ Examples at EUMETSAT with an anomaly database for MVIRI
- ➔ Examples below for ancient Nimbus imagers (left, center) and VTPR (right)



4 IR channels from MRIR, missing and bad data



HRIR on Nimbus 1, structured noise



VTPR (10 μm) on NOAA-4, geolocation errors

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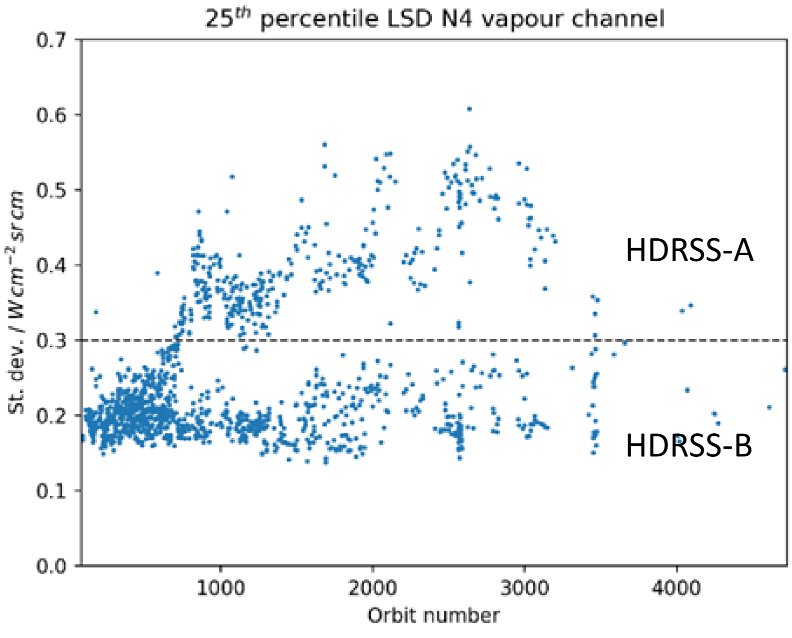
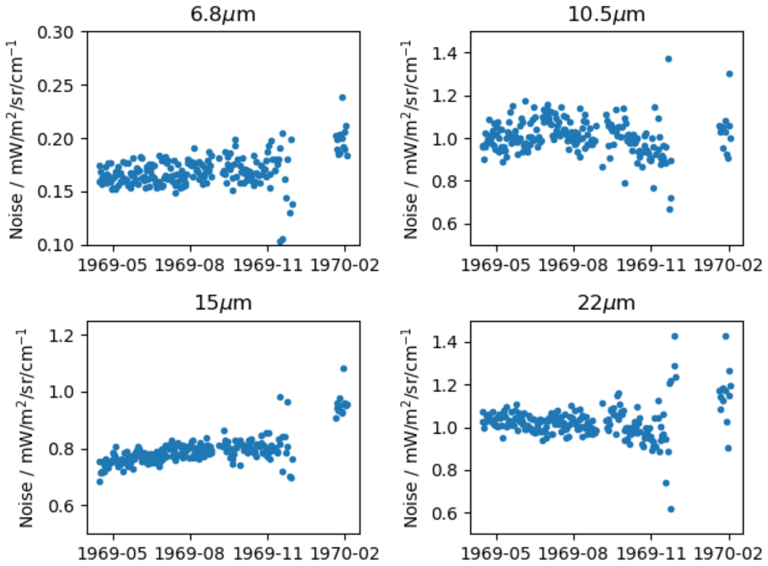
Noise estimates

Vary due to a number of causes (random component of uncertainty)

THIR noise varies dependent on which on-board tape is used



MRIR noise estimates



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HIRS reprocessing

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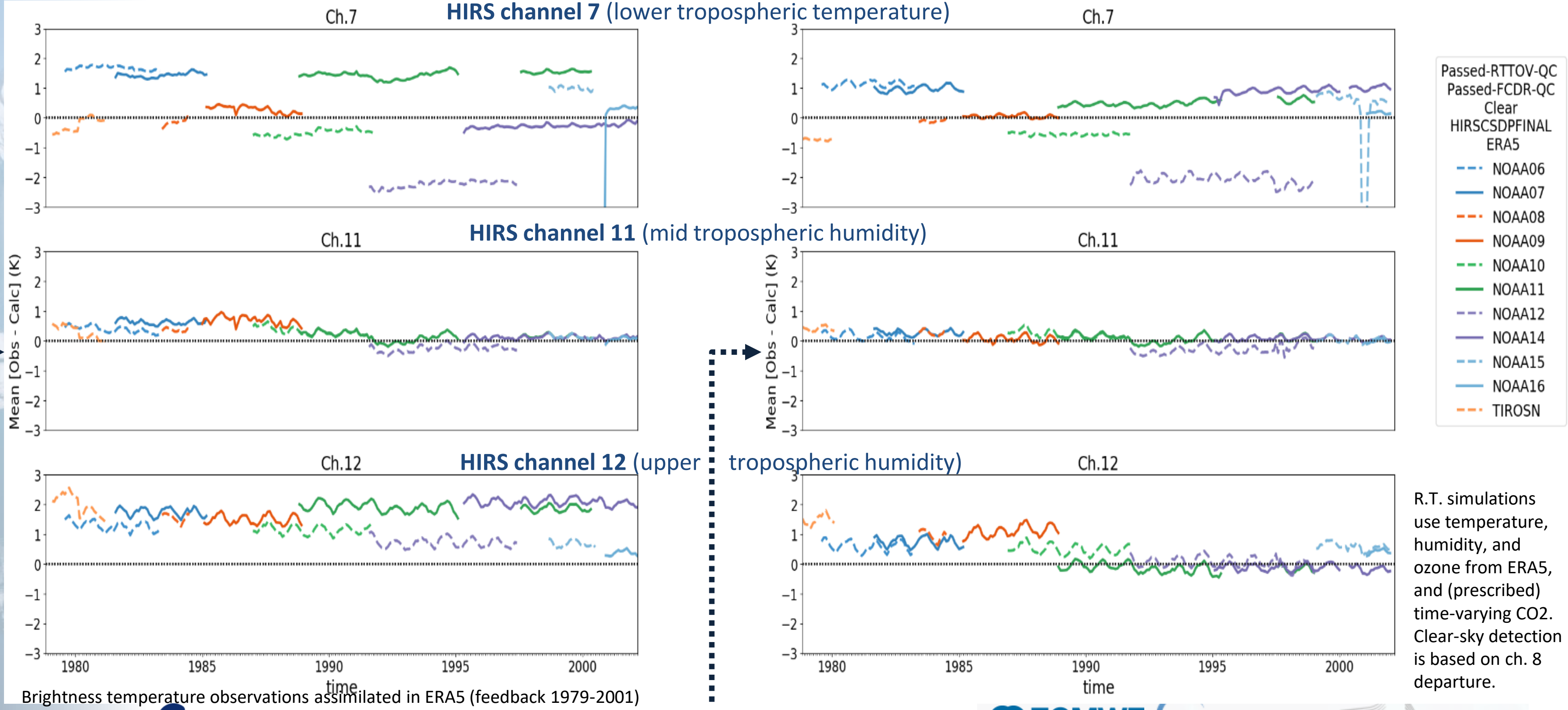
HIRS (ECMWF, reprocessed for ERA-40) minus ERA5 bg departures

New EUMETSAT HIRS FCDR minus Radiative transfer simulations (using ERA5)



R.T. simulations use temperature, humidity, and ozone from ERA5, and (prescribed) time-varying CO2. Clear-sky detection is based on ch. 8 departure.

Brightness temperature observations assimilated in ERA5 (feedback 1979-2001)

Mean differences (K)

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New HIRS FCDR: instrument noise (NEDT)

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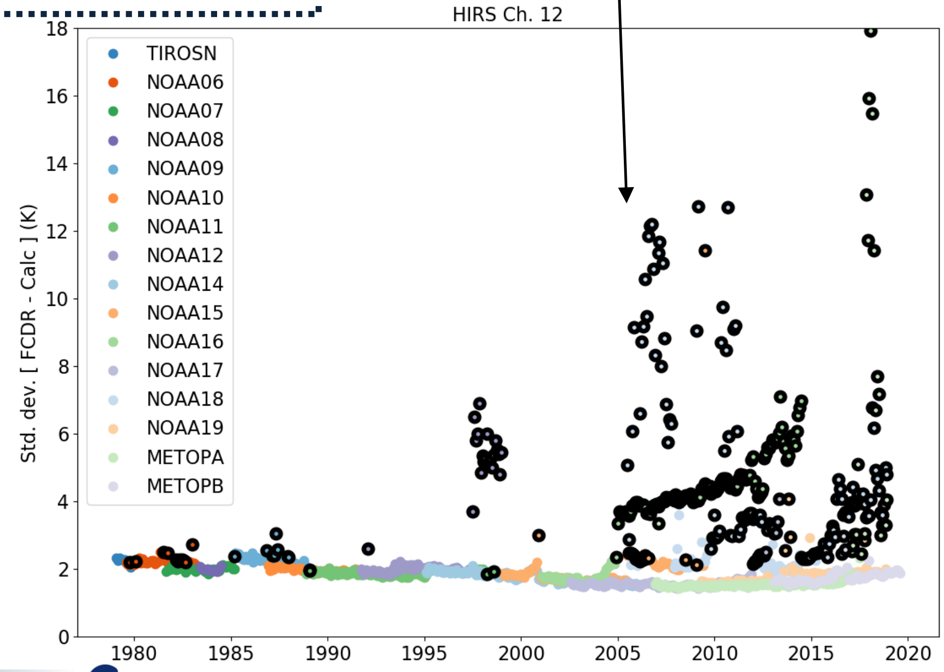
Std. dev. of differences between FCDR and radiative transfer simulations (K)

HIRS channel 12
(upper tropospheric humidity)

NEDT outside instrument specifications



- The NEDT (Noise Equivalent Delta Temperature) is computed and included in the FCDR.
- **Black circles** indicate NEDT exceeding the tabled instrument specs (*e.g.*, HIRS/3 specs below).

Table 3.2.1.1-2. HIRS/3 Spectral Characteristics.

Channel Number	Central Wavenumber (cm^{-1})	Wavelength (micrometers)	Half Power Bandwidth (cm^{-1})	Noise Equivalent Delta Radiance (NEΔN) $mW/(m^2\text{-sr-cm}^{-1})$
1	669	14.95	3	3.00
2	680	14.71	10	0.67
3	690	14.49	12	0.50
4	703	14.22	16	0.31
5	716	13.97	16	0.21
6	733	13.64	16	0.24
7	749	13.35	16	0.20
8	900	11.11	35	0.10
9	1,030	9.71	25	0.15

3-12 NOAA KLM Users Guide – April 2014 Revision

- Clear-sky radiative transfer simulations use ERA-Interim, plus prescribed (time-varying) CO_2.
- Scenes affected by clouds are removed here (based on ch. 8 departures).
- Scenes not passing the FCDR QC are removed here.

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SSM/T-2 FCDR: FIDUCEO uncertainties

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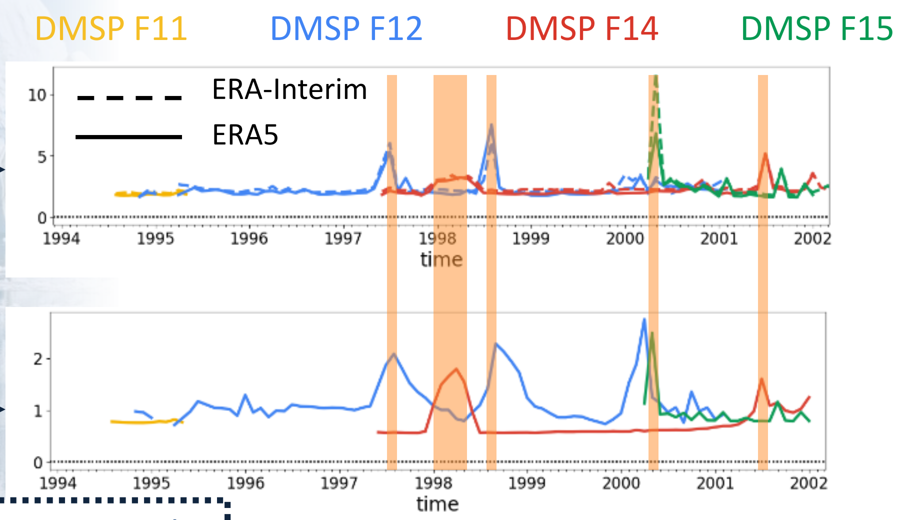
Std. dev. of differences between FCDR and radiative transfer simulations (K)

SSM/T-2 channel 183 ± 7 GHz
(lower tropospheric humidity)



FIDUCEO total uncertainty (K)

- SSM/T-2 predates AMSU-B, MHS.
- FCDR contains FIDUCEO uncertainties (cf. ***talk by C. Merchant***).
- FCDR Release 2: adds flags on cloud/rain contamination (based on SSM/I, HOAPS) and quality controls.
- Scenes affected by rain/clouds or not passing FCDR QC are removed here (based on FCDR Release 2 quality flags).
- Further intercomparisons required with traceable measurements, accounting for representativeness (***cf. talk by X. Calbet***)

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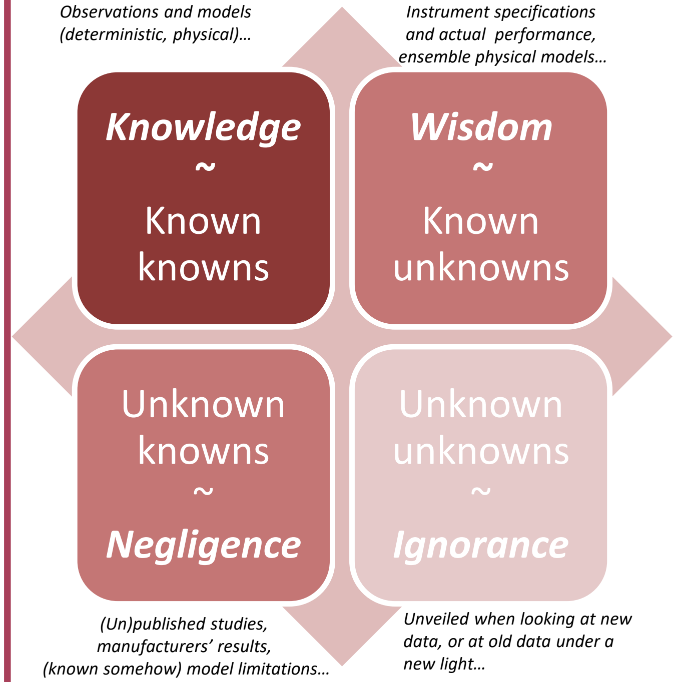
Conclusions and perspectives



Systematic part of the observation errors (bias)

- **Know what/when references are used for calibration**,
  if one could know more about actual calibration tolerance and cycle, may tell us more about what biases to expect?
  For in situ, WMO OSCAR/Surface (will eventually) do this
- **For satellite data: share predictors between satellites with same instruments**, when biases appear to follow similar patterns?

Random part of the observation errors (sigma_o)

- **Revisit estimates for old instruments**, in reanalysis?

Observation reprocessing

- **Provide uncertainties in FCDRs**, to help users make informed decisions?

Instrument/network specifications:

- **Link between WMO/OSCAR and RTTOV, including noise specifications?**
  e.g., as done for the SRF/spectral characteristics? This would help users exploit readily NEDT (sometimes) provided in the data
  Not solely for documenting past missions, but also for future missions (potentially: many small satellites, dev. and launched quickly)