Assimilation of satellite observations in global reanalysis: A double-edged sword?

P. Poli

with contributions from the reanalysis and satellite teams at ECMWF

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Observing the Earth from space: basic principles

An instrument

collects measurements,

from space,

while orbiting the Earth,

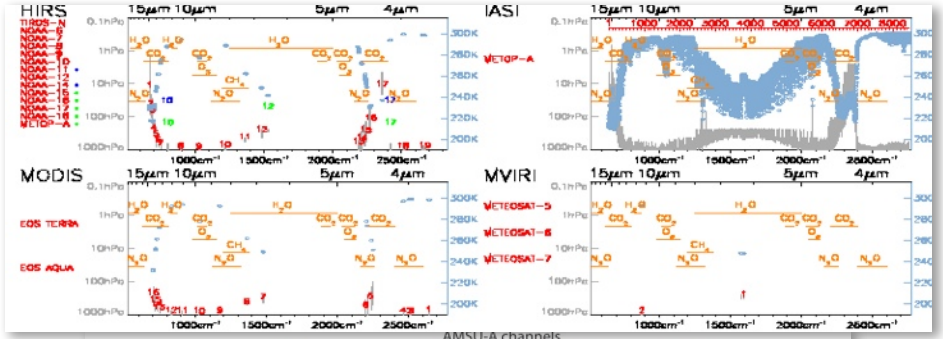
thereby remotely sensing the Earth's environment.

Questions addressed in this talk

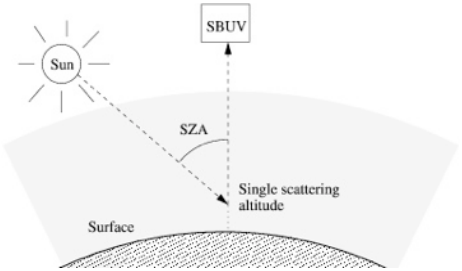
- What satellite data are used in atmospheric reanalyses? how many are used? how are they used? what are the main differences between the recent reanalyses?
- What is the impact of these data? (double-edged sword)
- How can we improve the situation?
- Future challenges and conclusions

Fundamental interactions (leaving aside strong and weak nuclear forces)

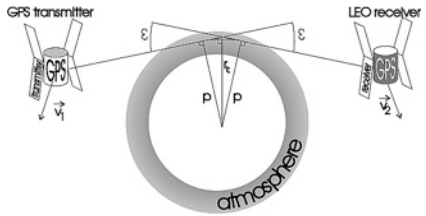
- Electromagnetism
  - Absorption and emission
    - Infra-red and micro-wave spectrometers collect spectral radiation, influenced by
      - Temperature, pressure,
      - Constituents (CO_2, H_2O, O_3, …),
      - Anything along the line-of-sight: Earth surface behind, cloud cover, aerosols, rain…



  - Scattering
    - Natural source: example Solar Ultra-Violet
    - Man-made source: radar, lidar



  - Refraction
    - Bending angles from GPS radio occultation



  - Diffraction
- Gravitation
  - Mass distributions in the Earth system

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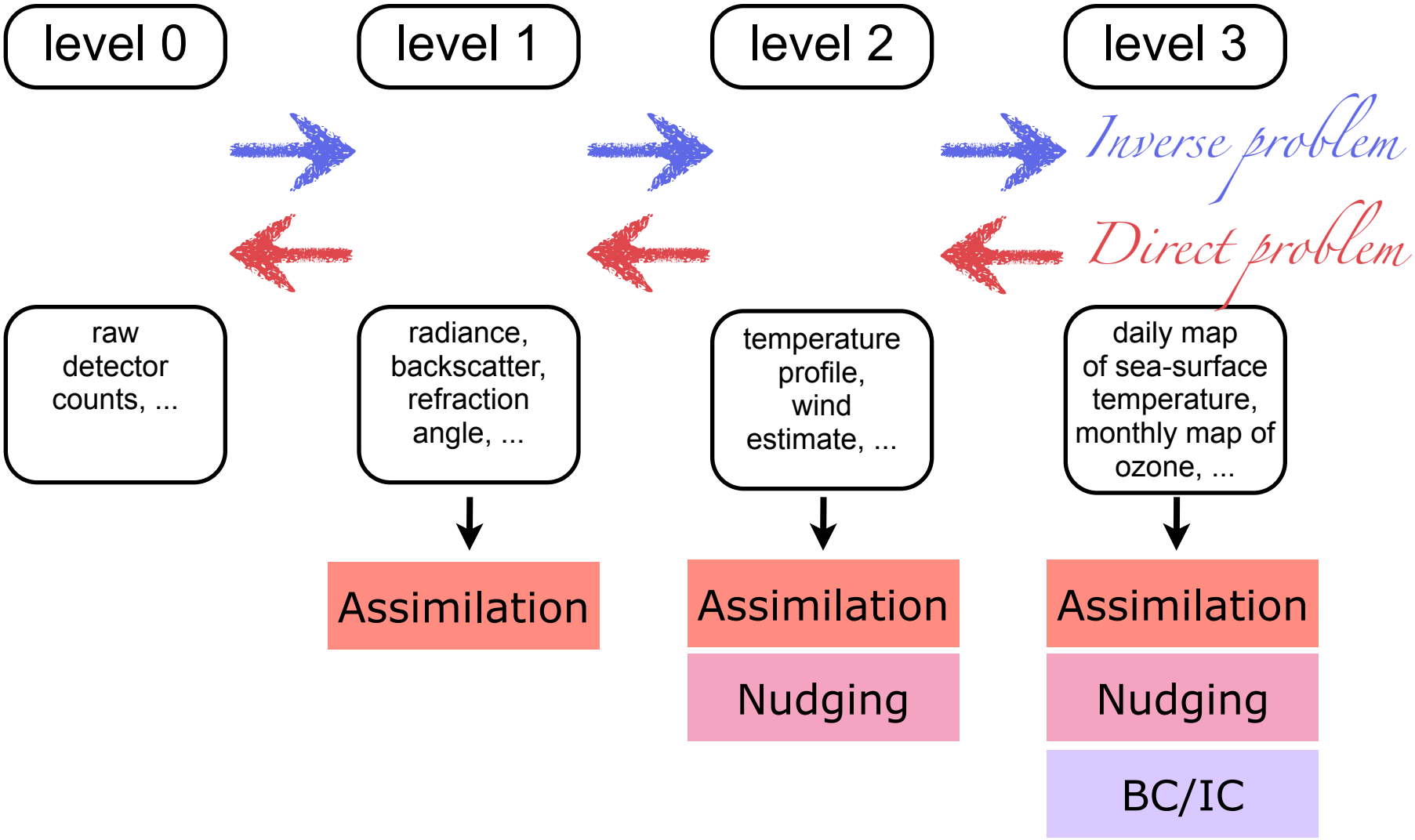
How satellite data are used



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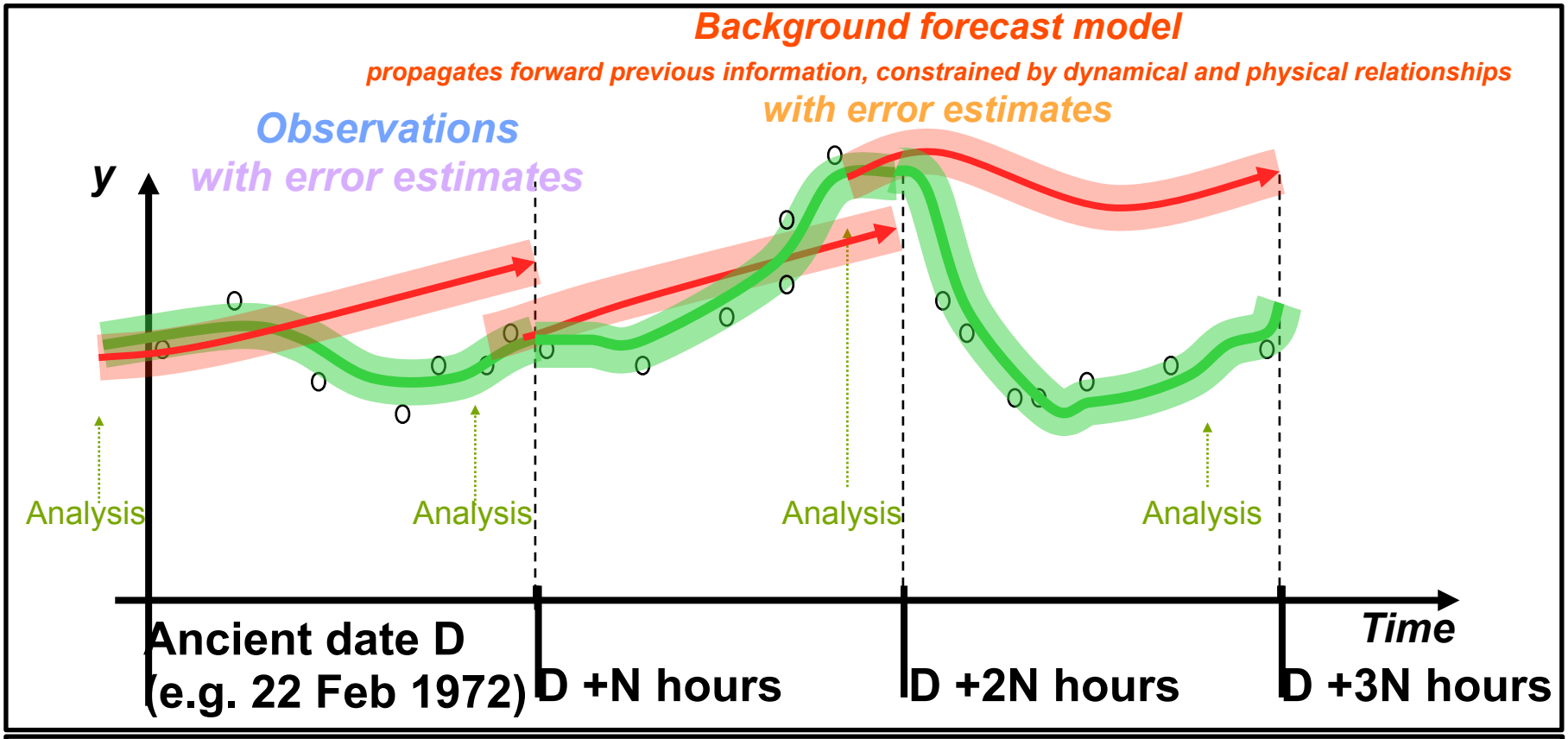
Reanalysis: reconstructing past weather in a forward-integration



$$\mathbf{J}(\mathbf{x},\hat{\mathbf{a}}) = (\mathbf{x}-\mathbf{x}_b)^T\mathbf{B}_x^{-1}(\mathbf{x}-\mathbf{x}_b) + (\hat{\mathbf{a}}-\hat{\mathbf{a}}_b)^T\mathbf{B}_{\hat{a}}^{-1}(\hat{\mathbf{a}}-\hat{\mathbf{a}}_b) +$$ **background constraint**

$$\left[\mathbf{y}^0 - h(M(\mathbf{x})) - b(M(\mathbf{x}),\hat{\mathbf{a}})\right]\mathbf{R}^{-1}\left[\mathbf{y}^0 - h(M(\mathbf{x})) - b(M(\mathbf{x}),\hat{\mathbf{a}})\right]$$ **observation constraint**

$M(\mathbf{x})$ Simulates atmospheric evolution in time

$h(.)$ Simulates observations, given atmospheric state

$b(.)$ Simulates observations biases

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Timeline of observations in ERA-Interim 1979-2012

Satellite data

Radiance

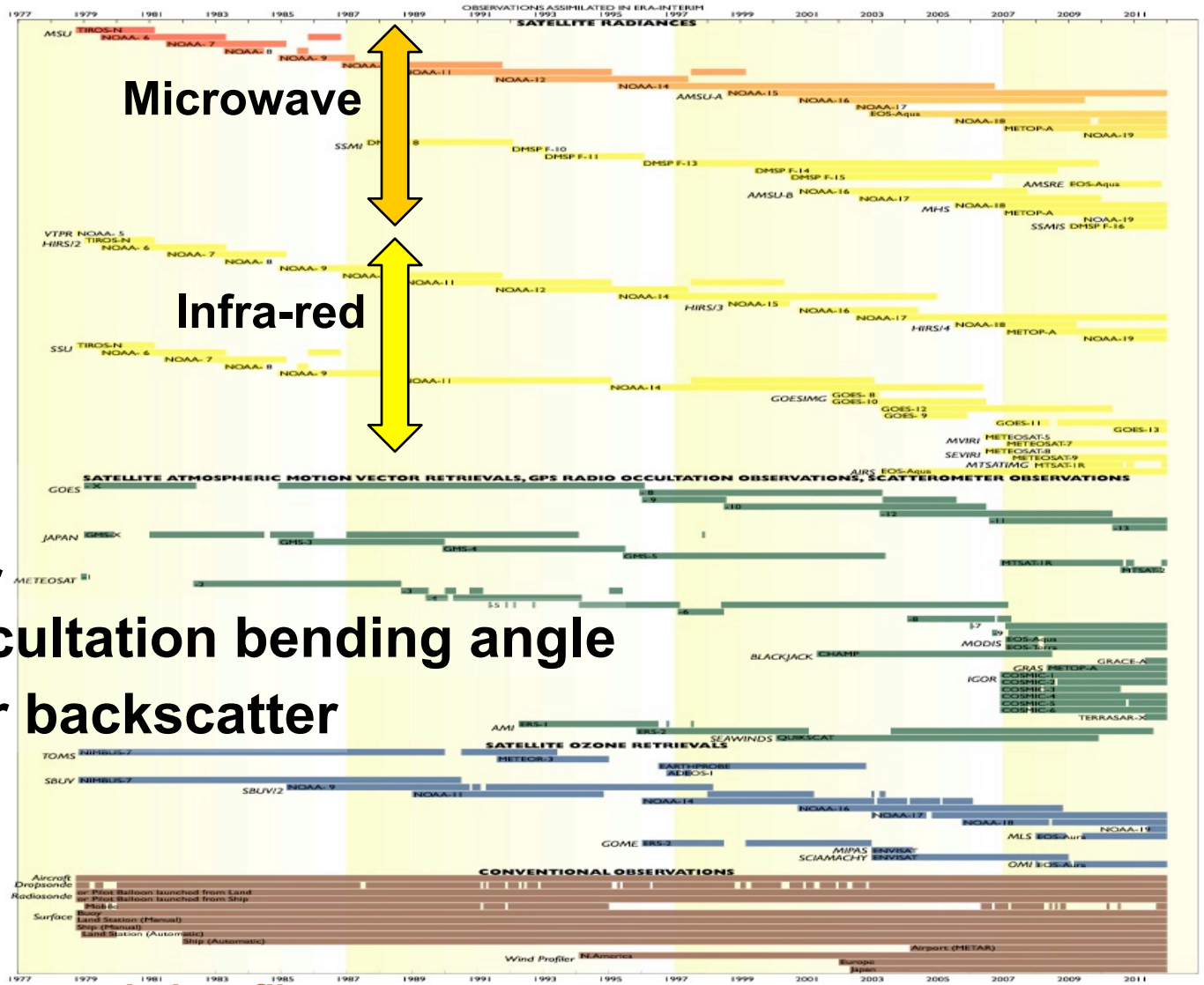
Atmospheric motion vector

GPS radio occultation bending angle

Scatterometer backscatter

Ozone

Radiosonde, aircraft, station, buoy, wind profiler, dropsonde



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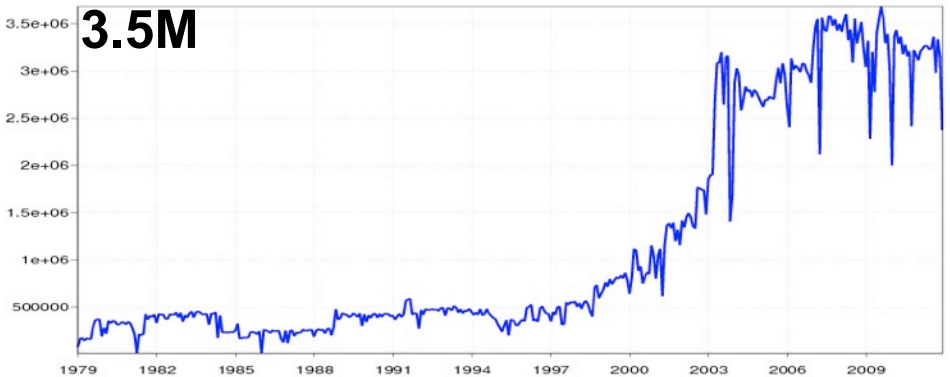
Satellite Data Coverage in ERA-Interim

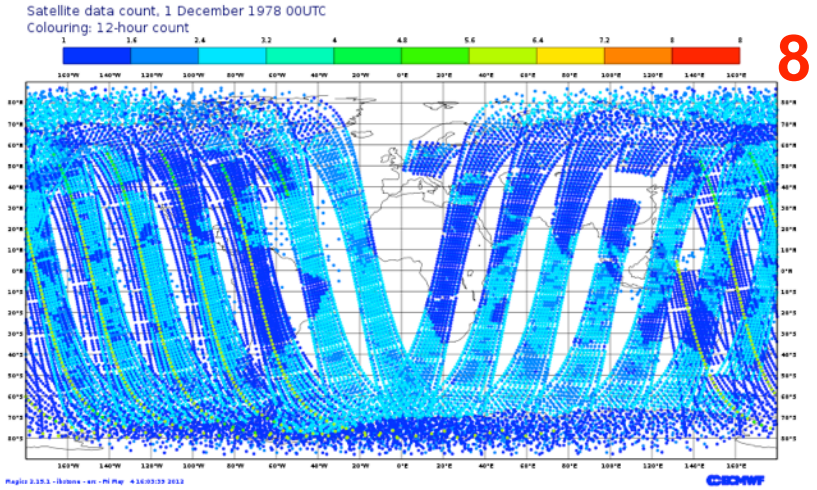
Number of satellite sensors/ AMV retrieval types

Number of data, every 12 hours

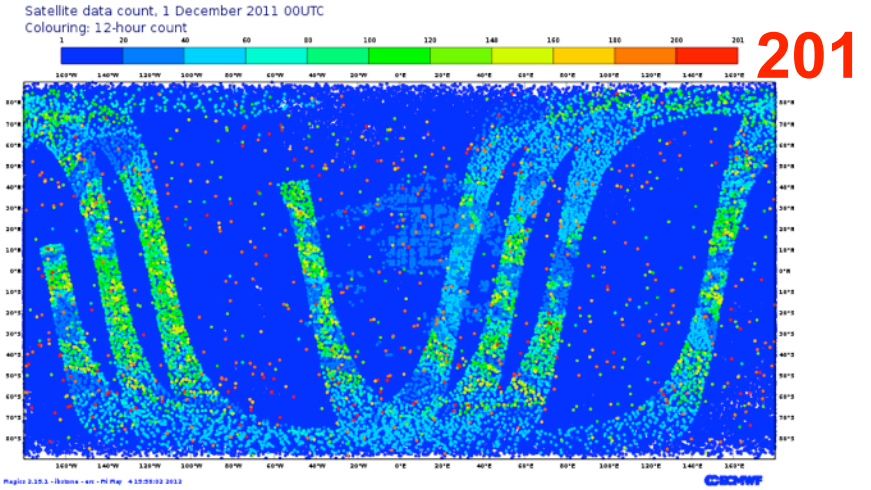


Number of satellite data used, 1 deg x 1 deg, 12-hour count

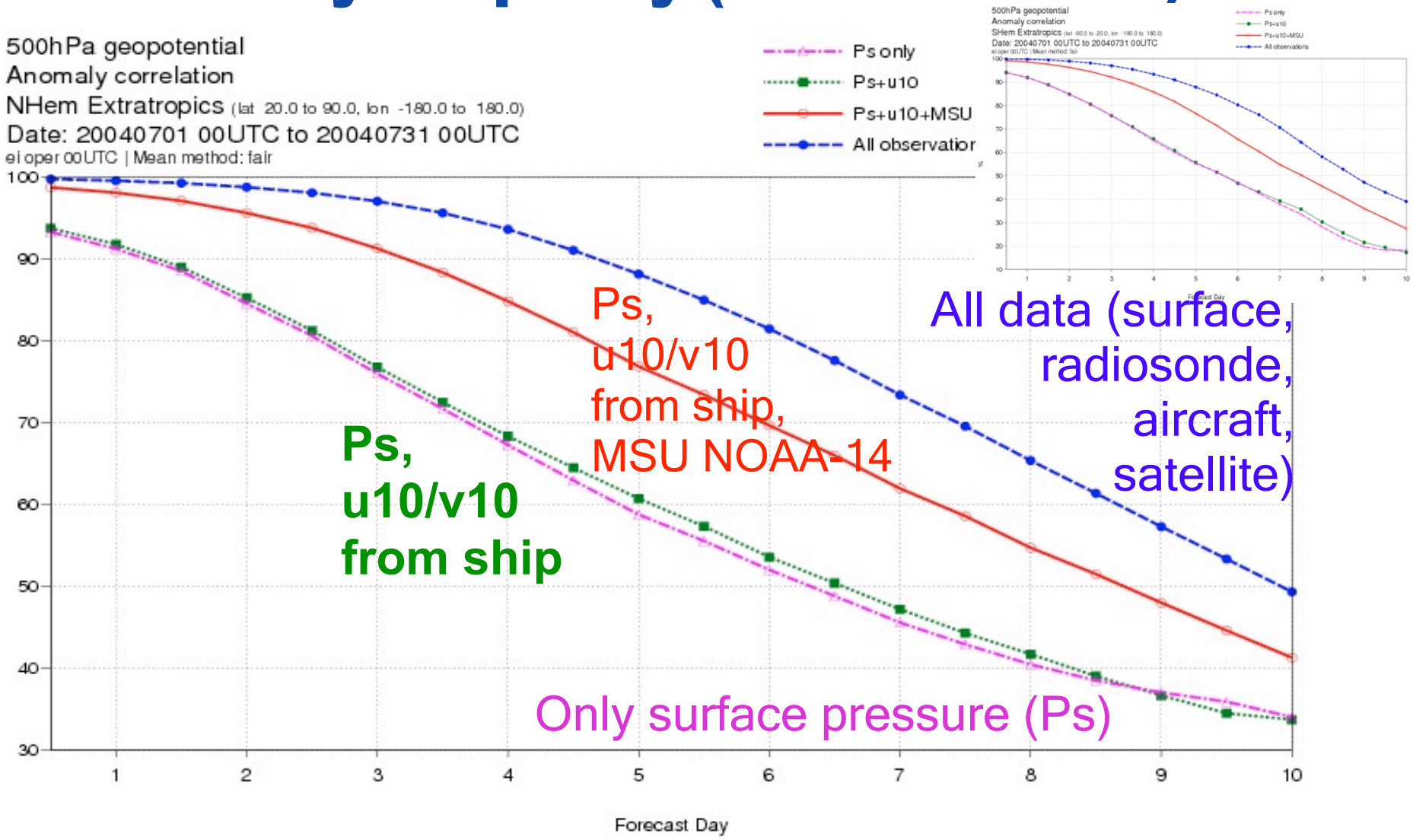
1 Dec 1978, 00UTC



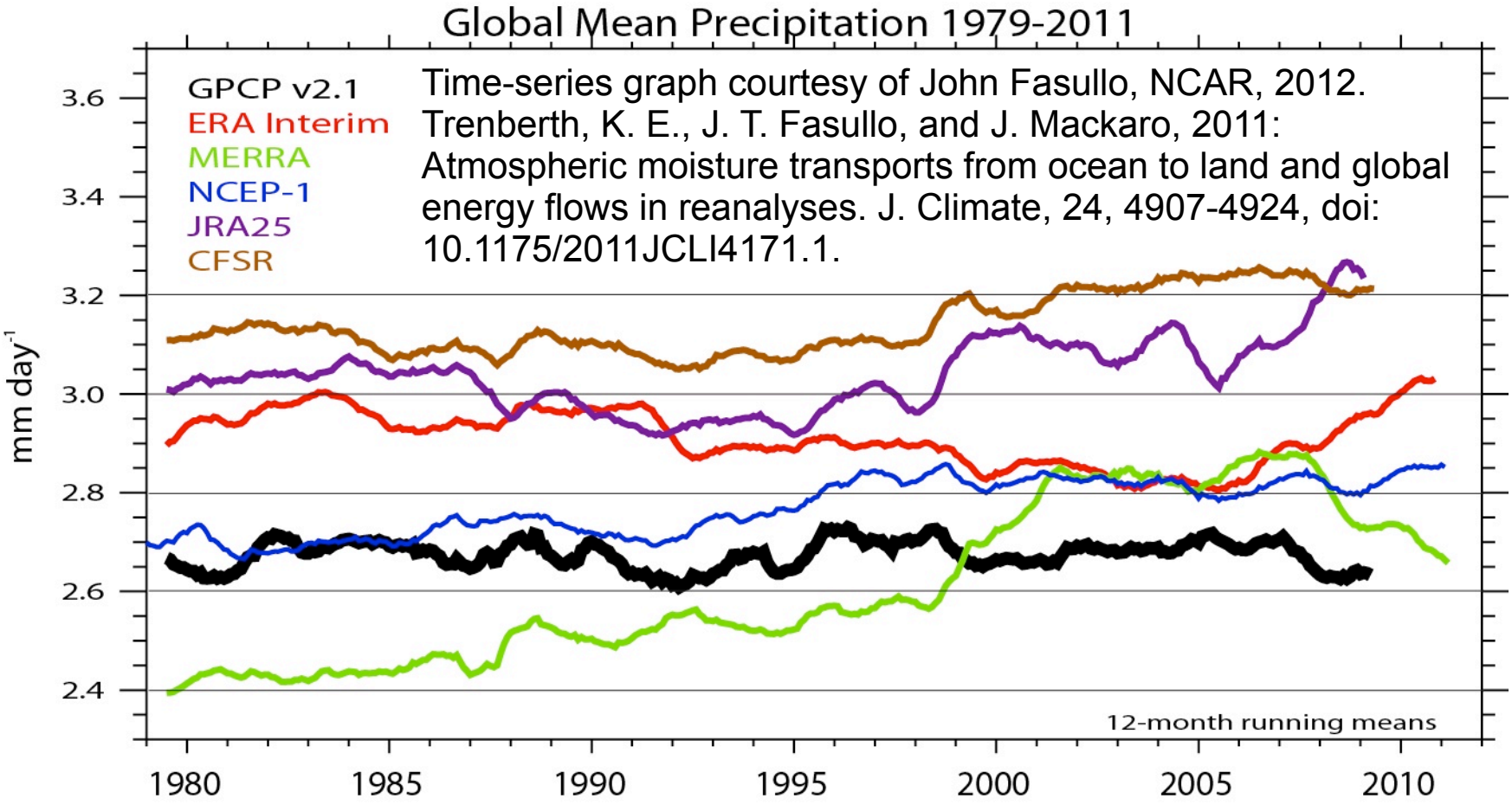
1 Dec 2011, 00UTC



Impact of a single microwave instrument on reanalysis quality (NOAA-14 MSU)



Precipitation in reanalyses and GPCP



ALREADY DISCUSSED THIS WEEK: MANY BREAKS IN THIS TIME-SERIES, DIRECTLY RELATED TO CHANGES IN THE SATELLITE INPUT: ATOVS FOR CFSR AND MERRA, SSM/I FOR ERA-INTERIM

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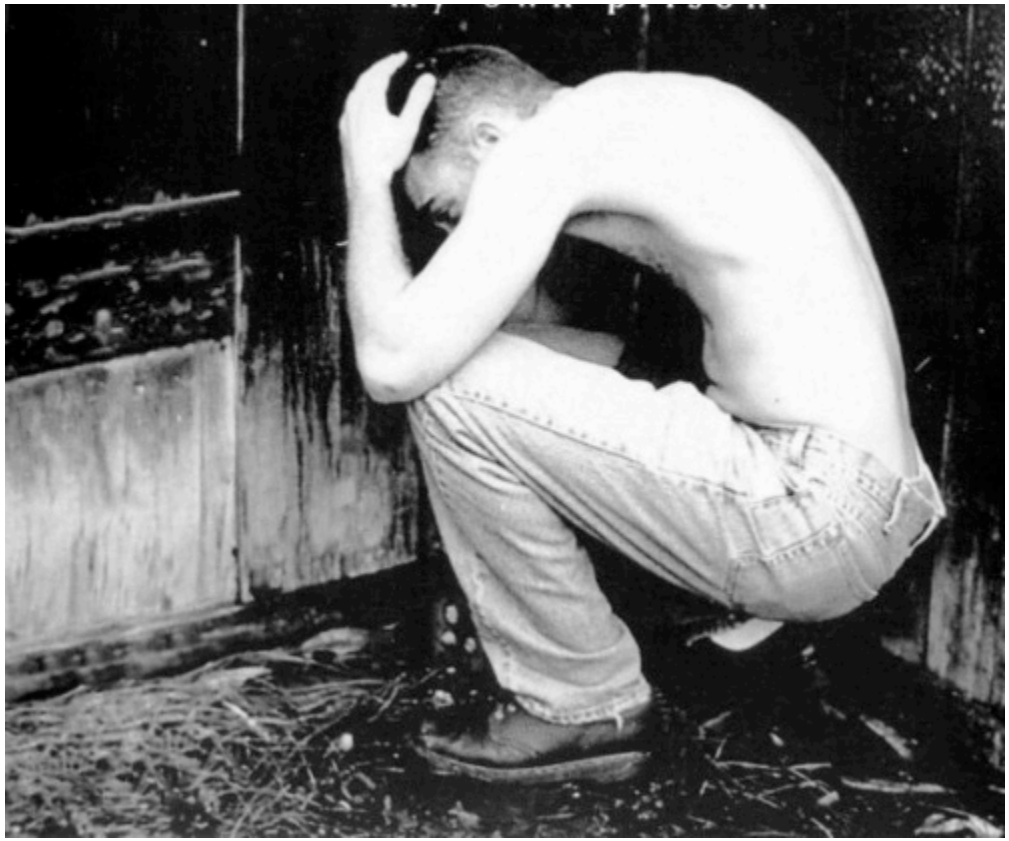
Satellite data assimilator in reanalyses?

(considering reconversion to in-situ-observations-only reanalyses?)



What data were actually used?

Material in this table mostly gathered from papers/websites, but I still asked verification – and found I hadn't gotten it completely right.

Thoughts: need to be more clear to users about what/how/when satellite data are used.

Overview of satellite data assimilated in modern reanalyses

Instrument, Observable	CFSR	MERRA	JRA-25	JRA-55	ERA-Interim
MSU Radiances	ch. 1,2,3,4 *For NOAA-10 to -14, NESDIS SNO corrected calibration coefficients; Exclusions: tighten qc limits in tropics and over high terrain; window test ch. 2*	ch. 1,2,3,4 *NESDIS SNO corrected calibration coefficients; Exclusions: snow, ice, mixed surfaces for ch. 1,2*	ch. 2, 3, 4 *Exclusions: land or rain for ch. 2-3*	ch. 2, 3, 4 *Exclusions: land or rain for ch. 2, land for ch. 3*	ch. 2, 3, 4 *Exclusions: land or rain for ch. 2, land for ch. 3*
AMSU-A Radiances	ch. 1-13, 15 *Exclusions: [illegible]timated cloud liquid water large for ch. 1-5, 15; Scattering index too large for ch. 1-6, 15; Channel 4 gross check large for ch. [illegible]-5,15; Ch. 6 gross check [illegible] for ch. [illegible] 6,15; Over high [illegible] (> 2000m) for ch. 1-5, 15; large fit to emissivity or Ts for ch. 1-5, 15*	ch.1-15 *Exclusions: [illegible]now, ice, mixed surfaces for ch. 1-6,15, no offset bias correct for ch.14*	ch. 4-13 *Exclusions: sea-ice or land for ch. 4-5, high terrain for ch. 6-7, rain for ch4-6*	ch. 4-13 *Exclusions: sea-ice or land for ch. 4-5, high terrain for ch.6-7, rain for ch4-8*	ch. 5-14 *Exclusions: high terrain for ch. 5-6, rain for ch. 5-7, no offset bias correct for ch14*
SSMI Radiances		ch. 1-7 *Ocean only*		ch. 1,3,4,6 *Exclusions: land, rain*	ch. 1-7 *Exclusions: land, rain*
AMSU-B / MHS Radiances	ch. 1-5 *Exclusions: scattering index too large, channel 1 fit too large, any channel failing gross check, high orography (>2000m).*	ch. 1-5 *Exclusions: snow, ice, mixed surfaces for ch. 1,2,5*	ch. 3-5 *Exclusions: land, sea-ice, rain*	ch. 3-5 *Exclusions: land, sea-ice, rain*	ch. 3-5 *Exclusions: sea-ice, rain, high terrain for ch. 3-4, land for ch. 5*
HIRS Radiances	ch. 2-15 *Exclusions: Over water wavenumbers > 2400 during day; high orography (> 2000); above model top; only use channels with signal above clouds; surface sensing channels with large difference.*	ch. 2-15 *Exclusions: land for channels 5-8*	ch. 2-7, 11, 12, 14, 15 *Exclusions: clouds or land for ch. 4 and above*	ch. 2-7, 11, 12, 14, 15 *Exclusions: land for ch. 4-7, 11, 14, 15, high terrain for ch. 12, clouds for ch. 3 and above*	ch. 2-7, 11, 12, 14, 15. *Exclusions: clouds, land for ch. 4-7, 11, 14, 15, high terrain for ch. 12*
SSU Radiances	ch. 1,2,3 *All channels bias-corrected.*	ch.1,2,3 *No offset bias correct. for ch.3*	ch. 1,2,3	ch. 1,2,3	ch. 1,2,3 *No offset bias correct. for ch.3*
GEO Radiances	GOES sounder, 5x5 1993-2007, 1x1 2007-	GOES sounder		GOES, METEOSAT, GMS, MTSAT imagers	GOES, METEOSAT, MTSAT imagers
SSMI Retrievals	Ocean surface wind speed	Ocean surface wind speed, Rain rate	Total column water vapor, Snow cover	Snow cover	Total column water vapor in rainy areas
Imager Upper-air winds	GOES, METEOSAT, GMS, MTSAT, MODIS	GOES, METEOSAT, GMS, MODIS	GOES, METEOSAT, GMS, MTSAT, MODIS	GOES, METEOSAT, GMS, MTSAT, MODIS	GOES, METEOSAT, GMS, MTSAT, MODIS
Scatt Ocean surf. wind	ERS, Quikscat, ACATW	ERS, Quikscat	ERS, Quikscat, ASCAT	ERS, Quikscat, ASCAT	ERS, Quikscat
Ozone Retrievals	SBUV V8 Retrievals	SBUV V8 Retrievals	TOMS, OMI (nudging)	TOMS, OMI (nudging)	TOMS, SBUV, GOME, MIPAS, SCIAMACHY, MLS, OMI
Other notable elements	AIRS, IASI, GPS radio occultation, AMSR-E, reprocessed ERS, reprocessed GMS, *AMSU-B NOAA-15*	TMI rain rate, AIRS, *AMSU-B NOAA-15*	Reprocessed GMS winds, AMSR-E Total column water vapor, HIRS NOAA-15 and later not used	Reprocessed winds from GMS/GOES-9/MTSAT (revised) and METEOSAT, Reprocessed radiances from GMS/GOES-9/MTSAT, TMI (from US), AMSR-E (from JAXA), GPS radio occultation, SSMIS, VTPR, HIRS NOAA-15 and later not used	GPS radio occultation, AIRS, SSMIS, AMSR-E, [illegible] *NOAA-18*
Input/checked by	J.Woollen, B.Kistler, D.Kleist, J.Derber	R. Gelaro, M. Bosilovich	S. Kobayashi		P. Poli

channels used over land

Had systematic impact in the 2006 ECMWF system

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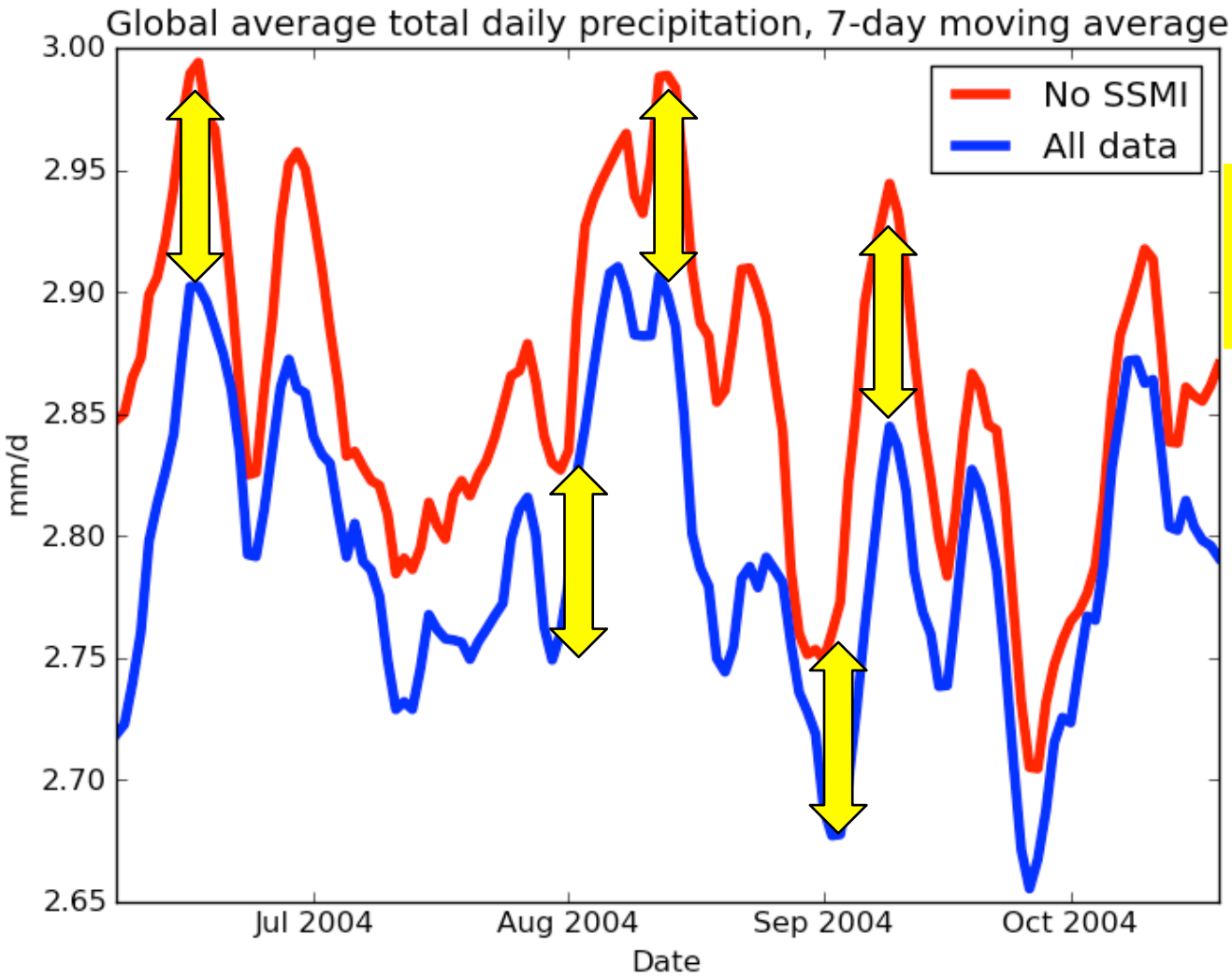
Microwave imager usage improvement: Impact on mean state

in current (2012) ECMWF data assimilation system



With current ECMWF system: ~0.07 mm/day

In ERA-Interim: was probably ~0.18 mm/day

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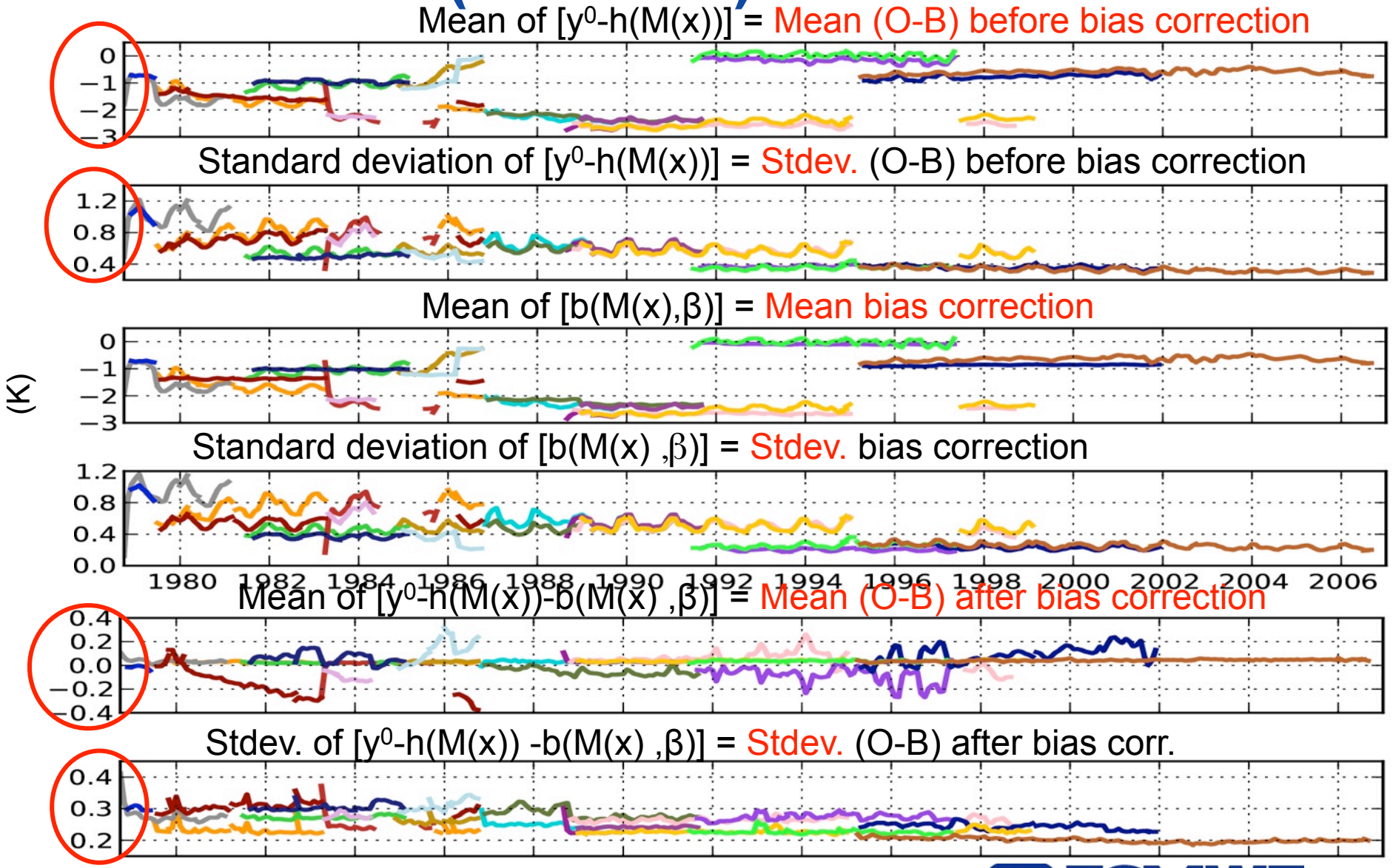
28-year time-series (1979-2006)

MSU channel 3 (a.k.a TTS) w.r.t ERA



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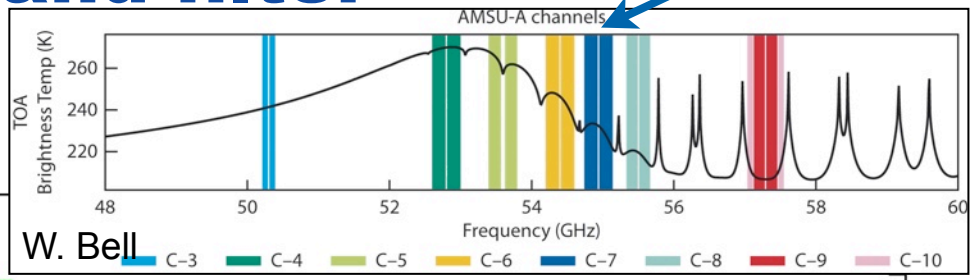
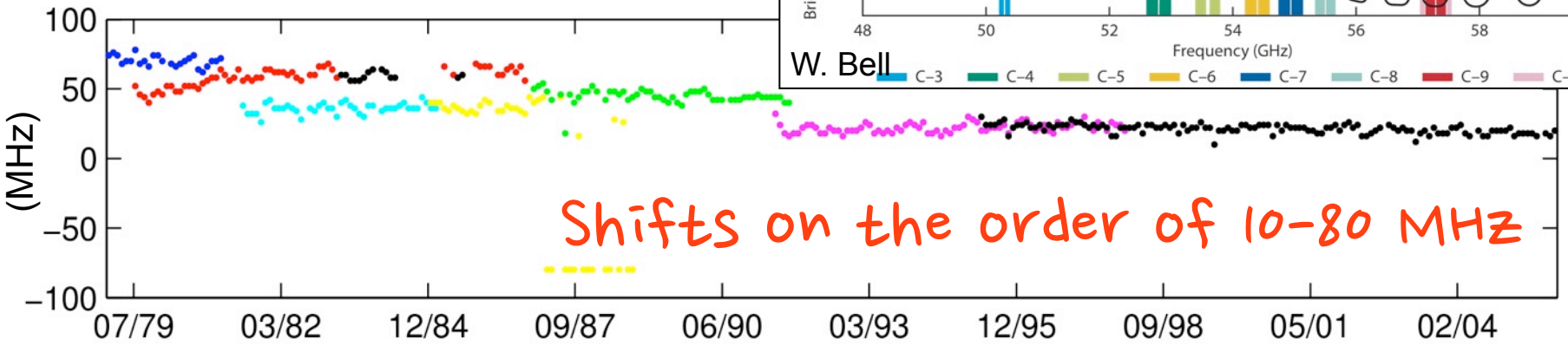
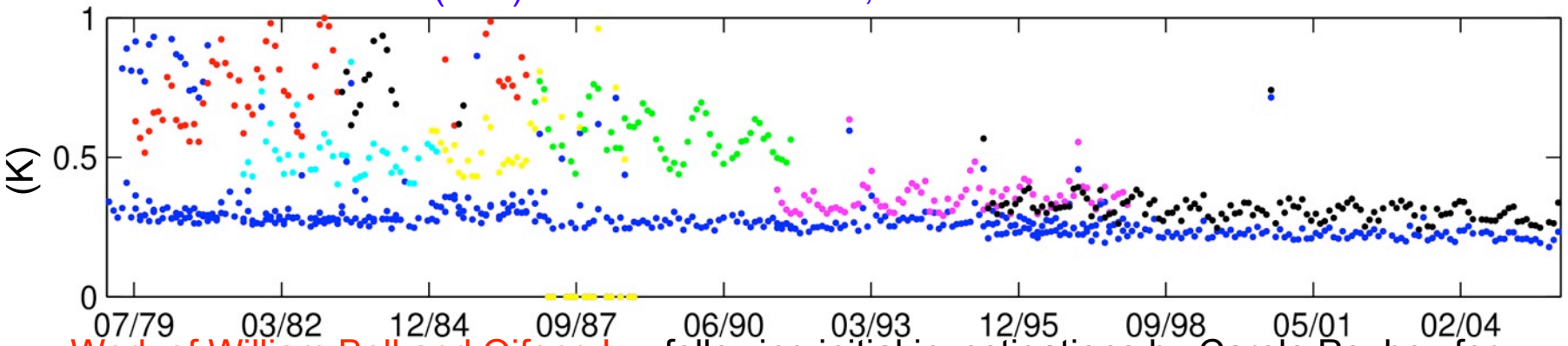
Microwave sounder usage improvement: accounting for passband filter frequency shift





Blue dots show stdv(O-B) w.r.t. to ERA-Interim, when shifts are used in radiative transfer



Work of William Bell and Qifeng Lu, following initial investigations by Carole Peubey for EUMETSAT post-MetOp mission specifications

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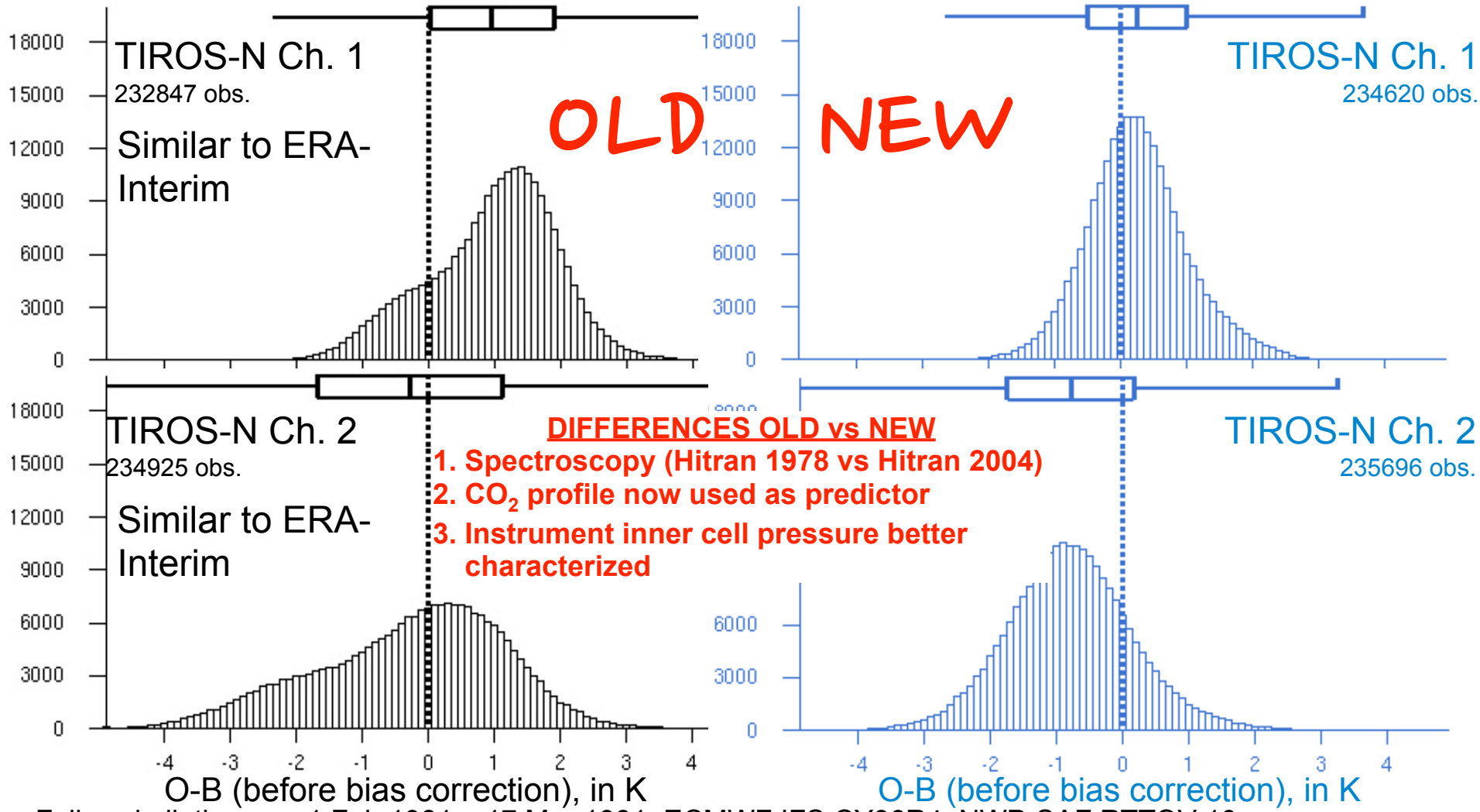
Infrared sounder usage improvement: Stratospheric Sounding Unit

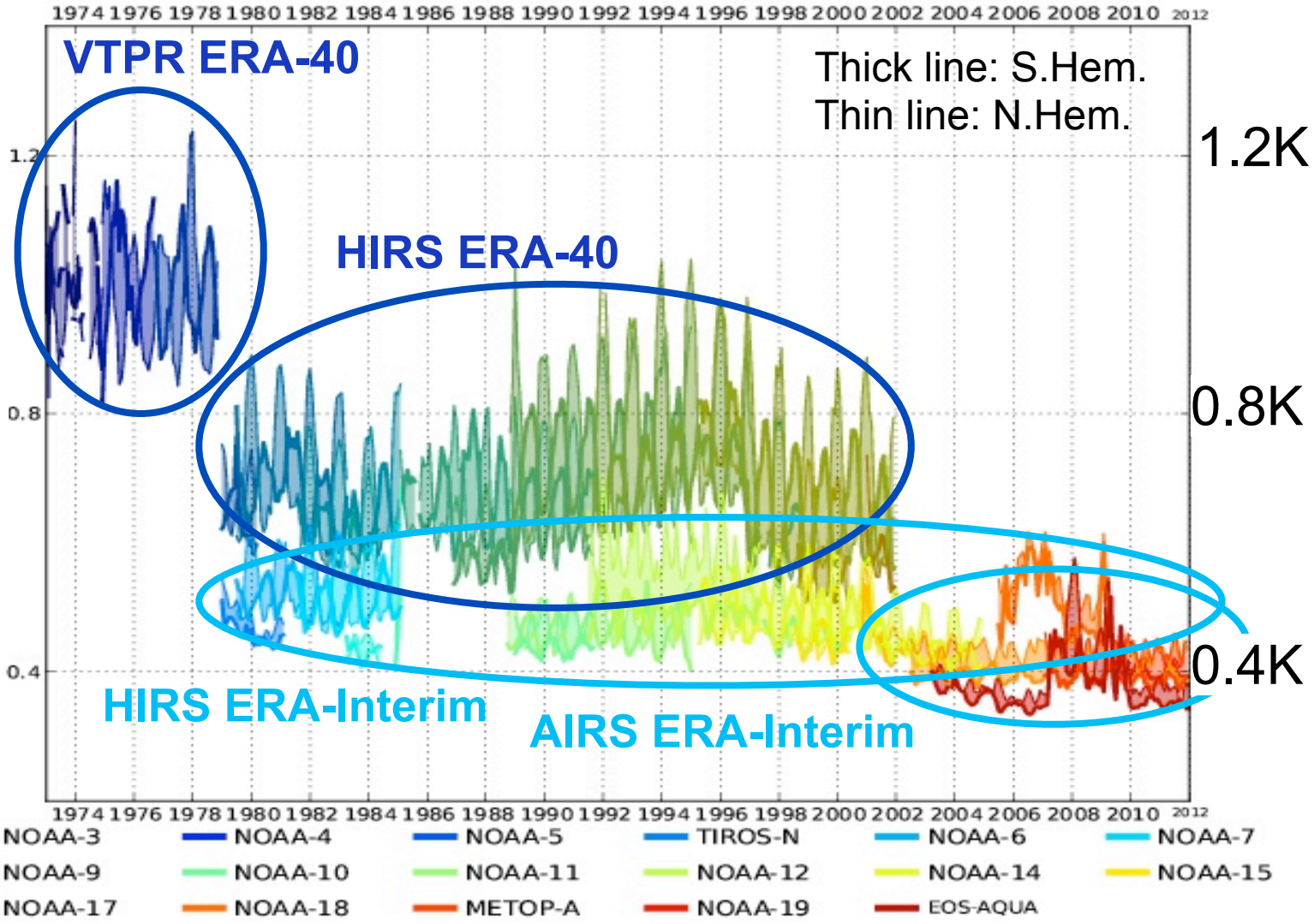


Full assimilation run, 1 Feb 1981 – 17 Mar 1981, ECMWF IFS CY36R4, NWP-SAF RTTOV-10, following work first conducted by S. Kobayashi

39-year time-series (1973-2012)

Infrared channel ~746 cm^{-1} std. dev. w.r.t. ERA

Stdev(O-B), without bias correction (K)



VTPR1, ch.7, 747.65 cm^{-1}
VTPR2, ch.7, 747.55 cm^{-1}
HIRS, ch.6, 748.27 cm^{-1}
AIRS, ch.333 746.01 cm^{-1}

HIRS Ch. 7 or

AIRS Ch. 333

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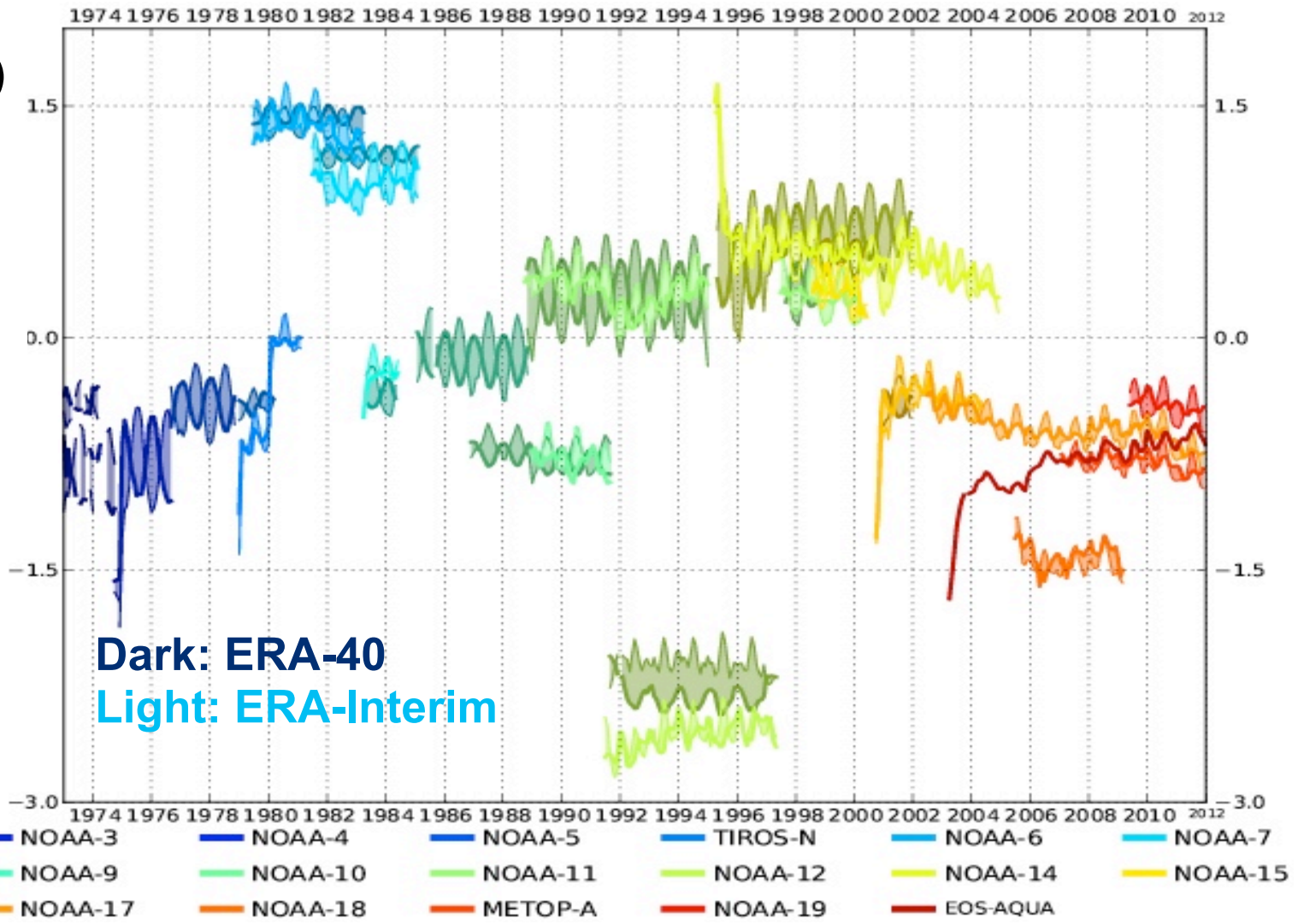
39-year time-series (1973-2012) of reanalysis bias corrections, infra-red channel near 746 cm^{-1}

Mean bias correction (K)



VTPR1, ch.7, 747.65 cm^{-1}
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HIRS Ch. 7 or

AIRS Ch. 333

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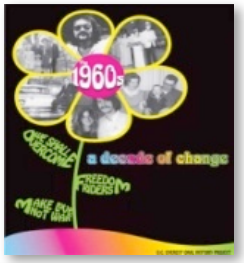
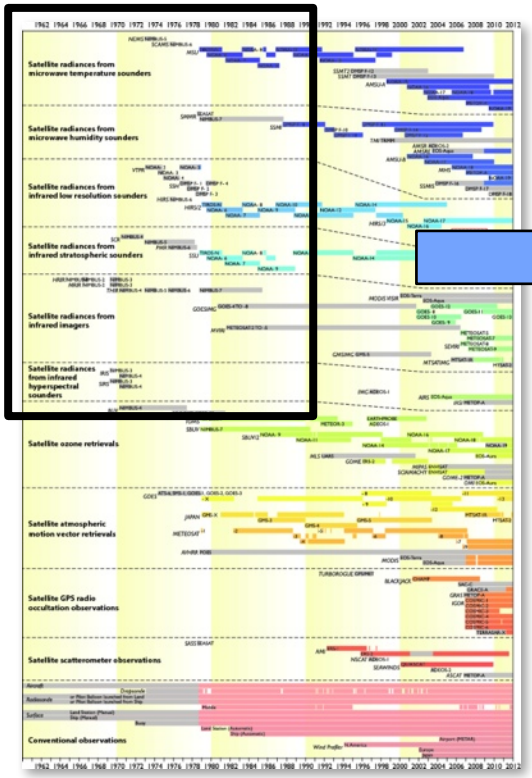
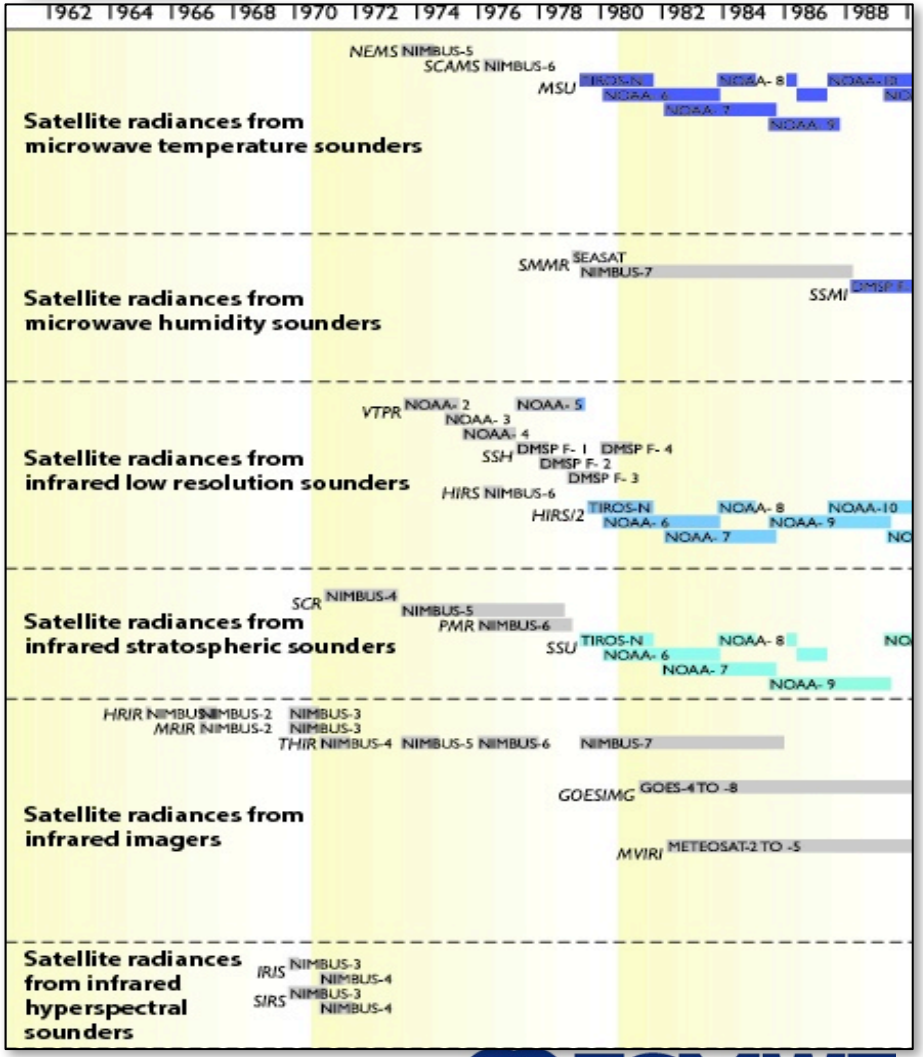
Satellite data since the 1960s







ERA-CLIM study, in collaboration with Met Office: R. Saunders, J. Viju, G. Kelly. See forthcoming talk by R. Saunders

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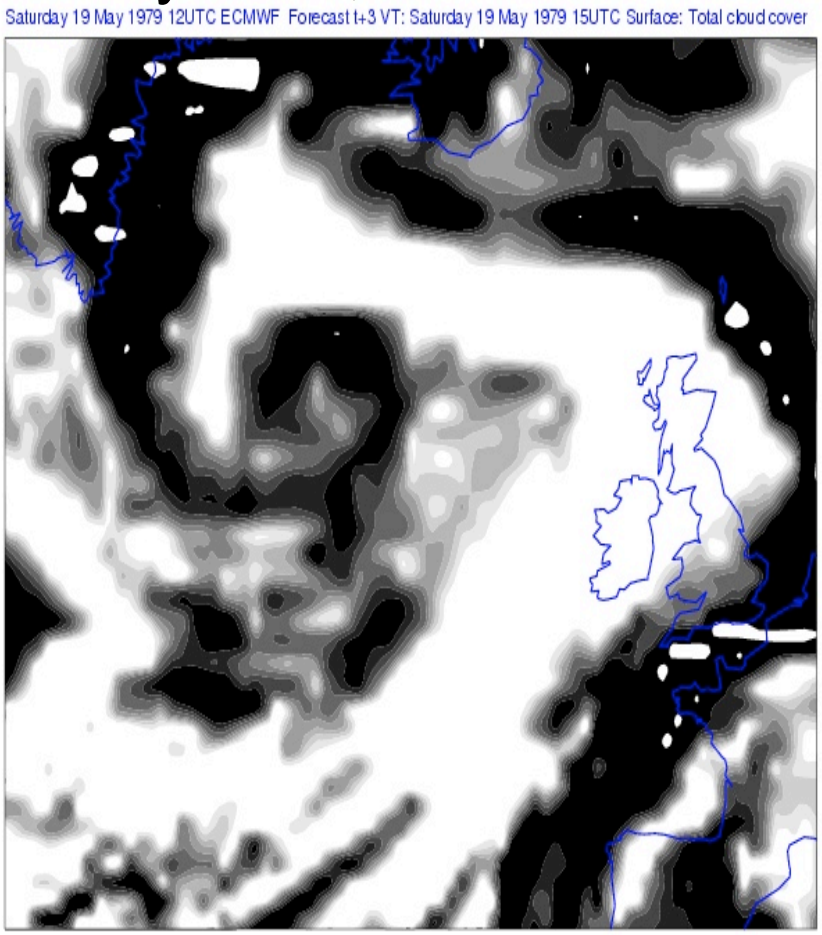
Millions of images, waiting to be assimilated

TIROS-N AVHRR VIS
19 May 1979, 15 UTC

ERA-Interim total cloud cover
19 May 1979, 15 UTC



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Questions regarding the future of satellite data use by reanalyses

- Towards *experimental* satellite-focused reanalyses, side-by-side with in-situ-focused reanalyses?
- Towards more assimilation/direct use of raw measurements, and less use of gridded / retrieved products?
- Towards pre-homogenized satellite inputs, side-by-side with efforts to better understand the physical roots of discrepancies between satellite records?
- Towards earlier use of satellite data, as far as the 1960s?

Satellite observations in reanalysis: Conclusions

- Satellite data used in reanalyses are of a varied nature.
- They are linked to some problems in modern reanalyses.
- **Satellite data are not the problem.**
- **They are (part of) the solution to our problem,** provided efforts are made to better use these observations.
- Extending the satellite record backwards for reanalysis, including reprocessing old data, would bring new information.
- International collaboration is essential to ensure a continuous record of Earth observations from space--
  ...towards a more balanced share of responsibilities for systematic Earth observation: EU, US, JP, BRICS?