European Commission

ECMWF Reanalsysis

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Rationale behind reanalysis: Consistency

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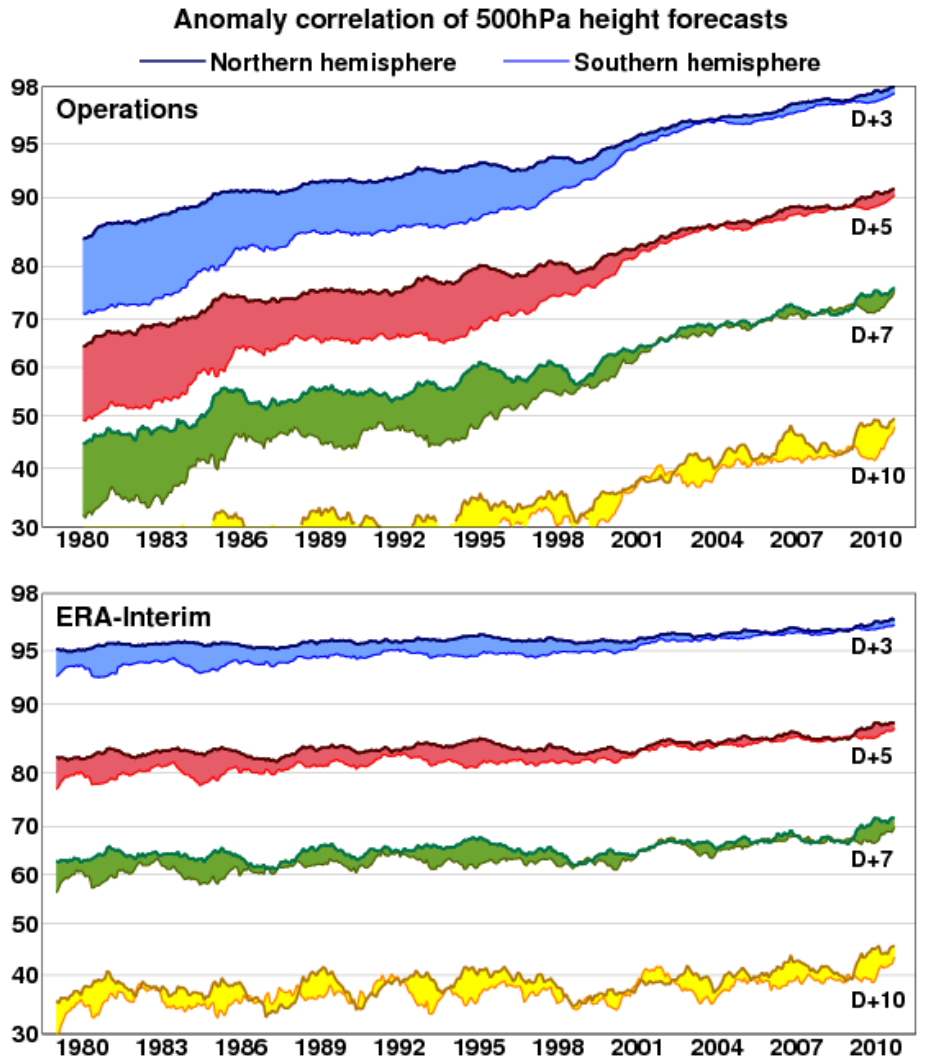
Consistent reconstruction of the atmosphere, waves (and ocean):

- merge observations into ***global fields,*** ***In situ and satellite data (mostly level 1b)***
- using the ***laws of physics***
- and appropriate ***bias correction*** scheme
- maintain the ***same system*** over the entire reanalysis period.

At lower resolution to ***keep affordable***



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Two classes of Reanalysis

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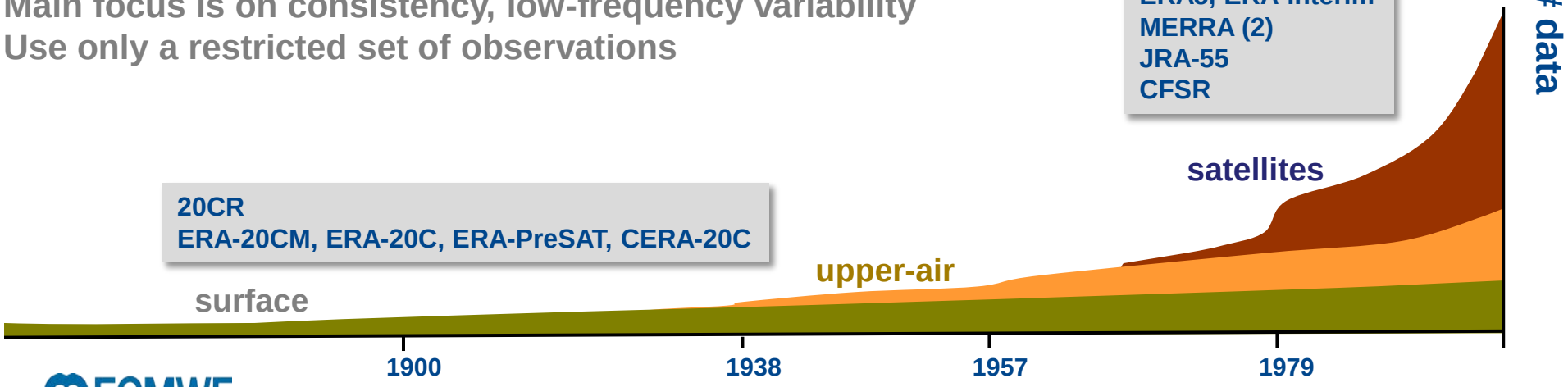
Reanalyses of the modern observing period (~30-50 years):

- Produce the best state estimate at any given time (as for NWP)
- Use as many observations as possible, including from satellites
- Closely tied to forecast system development and evaluation
- Can support product updates in near-real time

Extended climate reanalyses (~100-200 years):

- As far back as the instrumental record allows
- Pioneered by NOAA-CIRES 20th-Century Reanalysis Project
- Long perspective needed to assess current changes
- Main focus is on consistency, low-frequency variability
- Use only a restricted set of observations



Reanalyses Produced at ECMWF

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Atmosphere/land including ocean waves

1) 1979 - 1981 FGGE	2) 1994 - 1996 ERA-15	**3) 2001** - 2003 ERA-40	4) 2006 - … ERA-Interim	5) 2016 - … ERA5

Ocean including sea ice

2006 ORAS3	2010 - … ORAS4	2016 - … ORAS5

ERA CLIM / ERA CLIM 2

Centennial **Q1 2017**

2013 - 2015 ERA-20CM/20C	2016 CERA-20C

Enhanced land

2012 ERA-Int/Land	2014 ERA-20C/Land	**2017 - …** ERA5L

Atmospheric composition

2008 - 2009 GEMS	2010 - 2011 MACC	2017 - … CAMS

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Reanalysis: users world-wide

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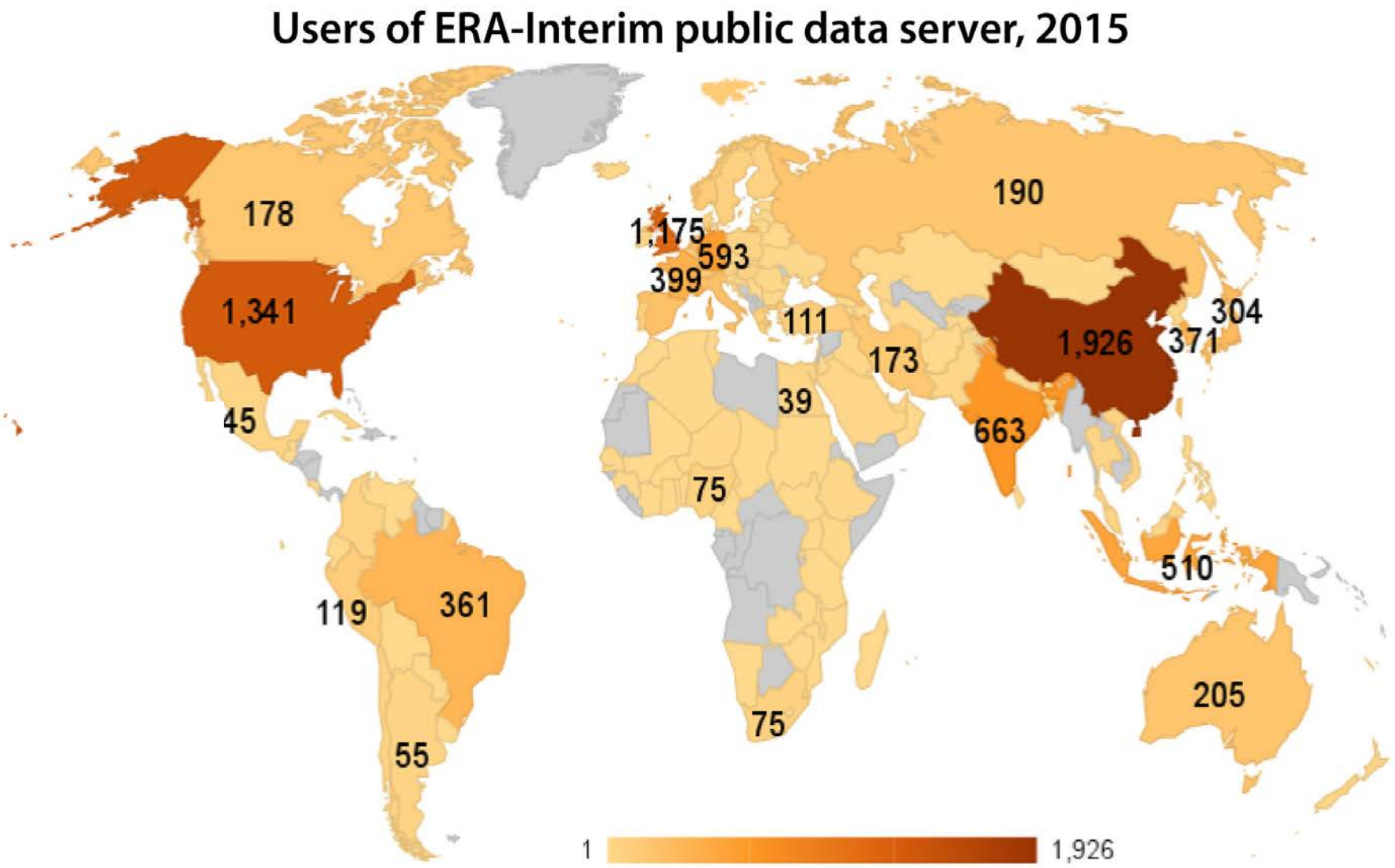

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What is new in ERA5?

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	ERA-Interim	ERA5
Period	1979 - present	1979 - present
Start of production	August 2006	Jan 2016, 1979-NRT end 2017
Assimilation system	2006 technology	Current state of the art
Model input (radiation and surface)	As in operations, *(inconsistent sea surface temperature)*	***Appropriate for climate***, e.g., evolution greenhouse gases, volcanic eruptions, sea surface temperature and sea ice
Spatial resolution	79 km globally 60 levels to 10 Pa	***31 km globally*** 137 levels to 1 Pa
Uncertainty estimate		Based on a 10-member ***ensemble*** at 62 km
Land Component	79km	9km
Output frequency	6-hourly Analysis fields	***Hourly*** (three-hourly for the ensemble), ***Extended list of parameters*** ***~ 5 Peta Byte***
Extra Observations	Mostly ERA-40, GTS	Various ***reprocessed CDRs***, ***latest instruments***
Variational Bias corrections	Satellite radiances Radiosondes: RASE	Also ozone, aircraft, surface pressure, Radiosondes: RICH + Solar-Elevation (RISE) operational bias control from 2015

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The evolving observing system

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Newly reprocessed data sets

Radiances: SSM/I brightness temp from CM-SAF
MSG from EUMETSAT

Atmospheric motion vector winds: METEOSAT, GMS/GOES-9/MTSAT, GOES-8 to 15, AVHRR METOP and NOAA

Scatterometers: ASCAT-A (EUMETSAT),
ERS 1/2 soil moisture (ESA)

Radio Occultation: COSMIC, CHAMP, GRACE, SAC-C, TERRASAR-x (UCAR)

Ozone: NIMBUS-7, EP TOMS, ERS-2 GOME, ENVISAT SCIAMACHY, Aura MLS, OMI, MIPAS, SBUV

Wave Height: ERS-1,ERS-2, Envisat, Jason

Data that were not used by ERA-Interim

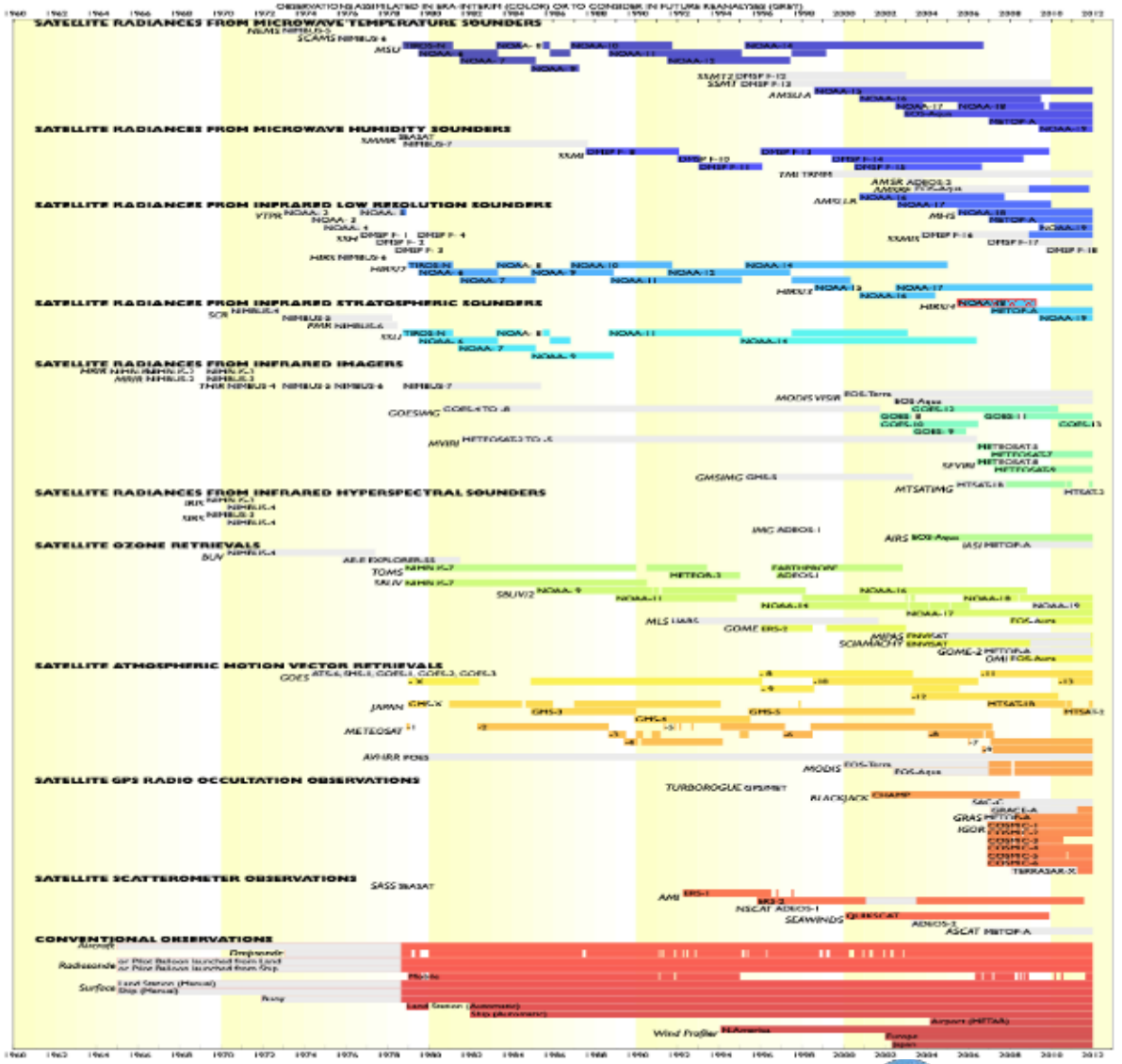
(due to lack of infrastructure)

IASI, ASCAT, ATMS, Cris, Himawari, …

Typically the latest instruments:
ERA5 is more future proof!

Improved data usage

all-sky vs clear-sky assimilation,
latest radiative transfer function …



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Historical AMVs: Level 2 Wind

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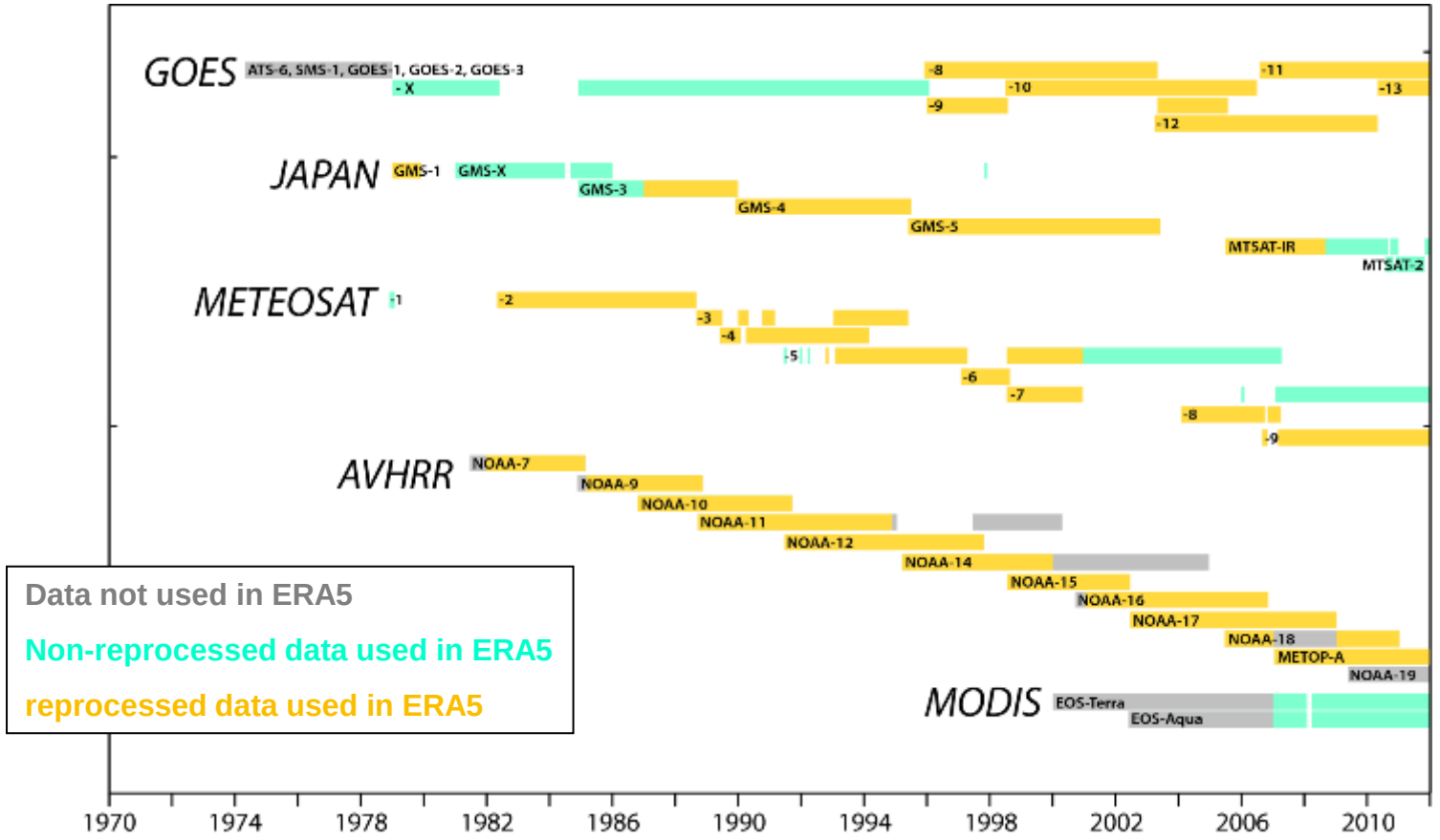
- **Sustained effort of the AMV community to reprocessed data: large fraction of the available datasets have now been reprocessed**
- **Effort continued at EUMETSAT within *ERACLIM-2* and the *C3S provision of reprocessed satellite data* (updated algorithms, MFG/MSG, dual and polar METOP AVHRR, NOAA AVHRR).**



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Historical AMVs

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Reprocessed AMVs benefit to the quality of the reanalysis. AS, but as expected, the impact get less weaker for recent dates due to the dense observational network

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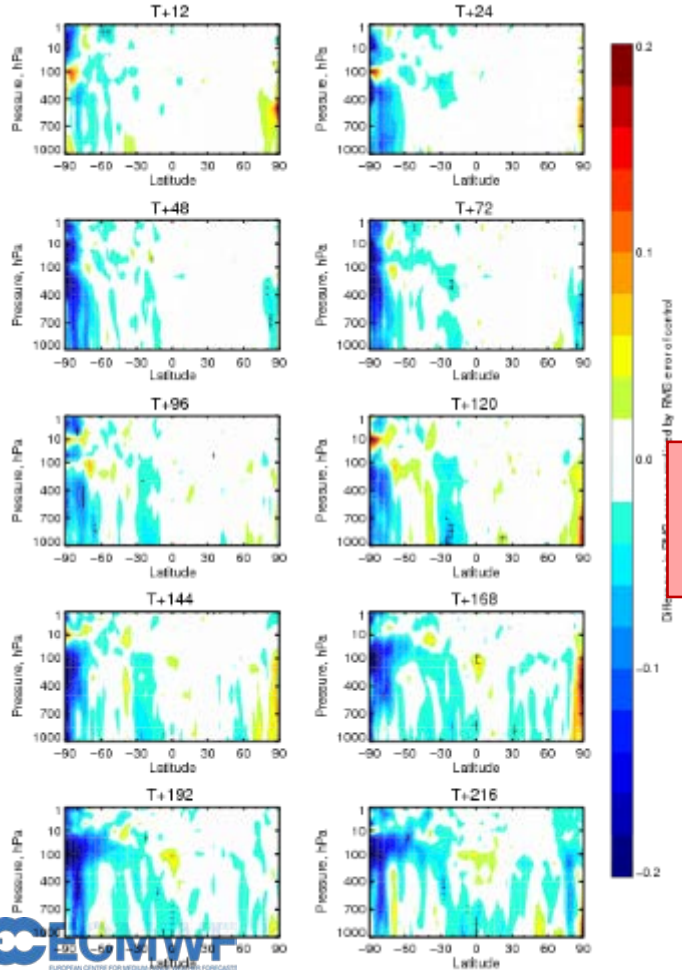
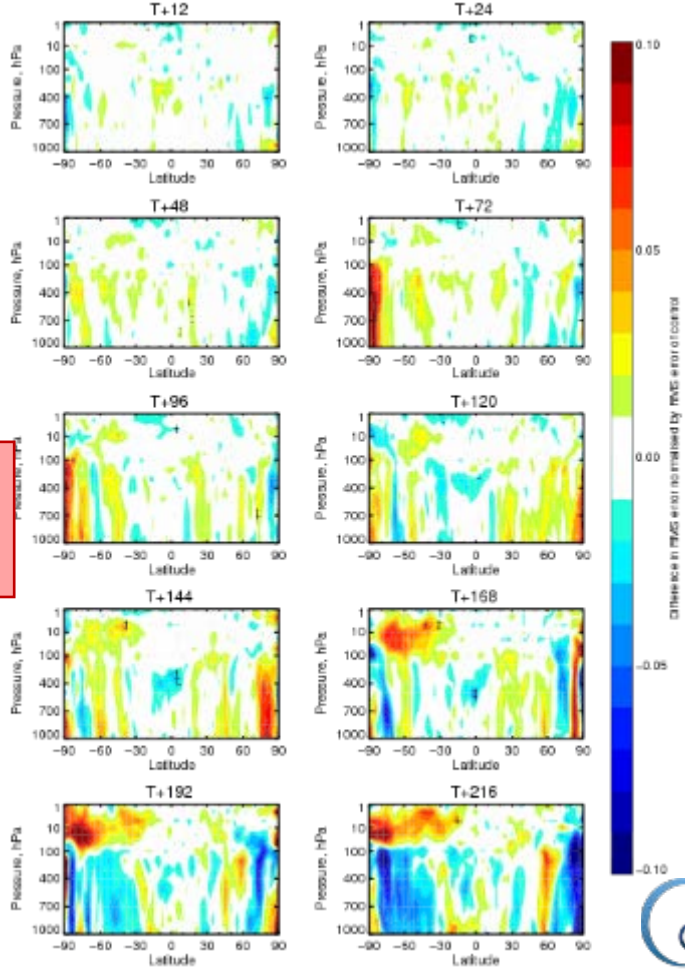
Difference in forecast RMSE (VW)

1983: "NOAA7" *minus* "no NOAA7"



Reprocessing of the oldest datasets particularly crucial.

2009: "NOAA18" *minus* "no NOAA18"



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Ozone, ERA-Interim vs ERA5

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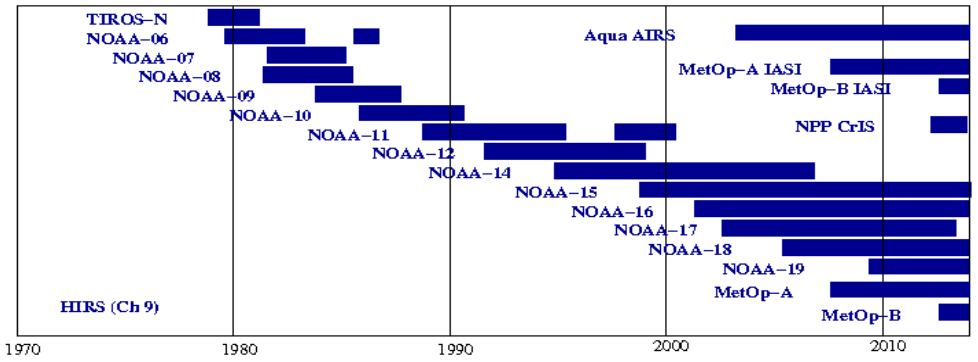
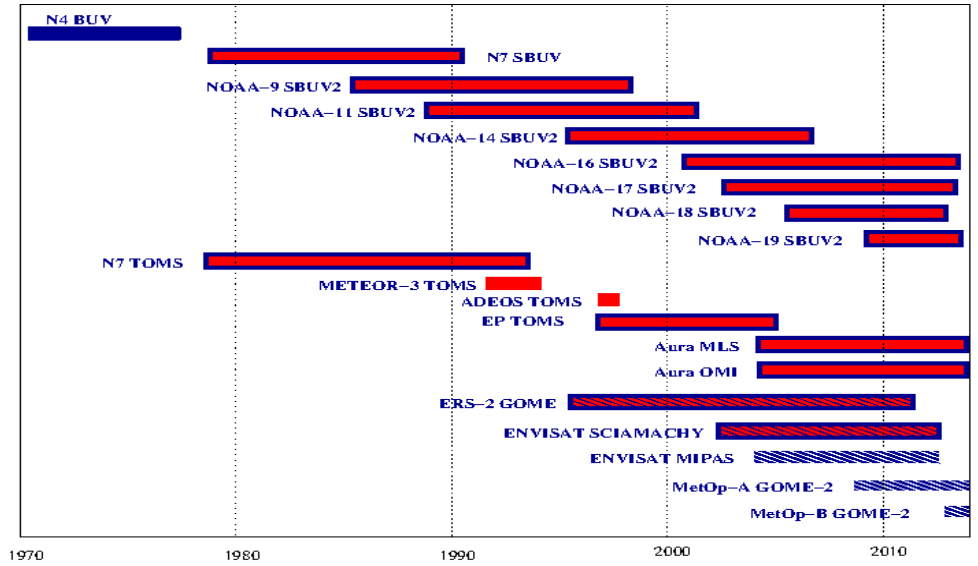
Level 1b



Level 2



Used / same version

Used / new version

Never used

Available from CCI

Rossana Dragani

Plus variational bias correction

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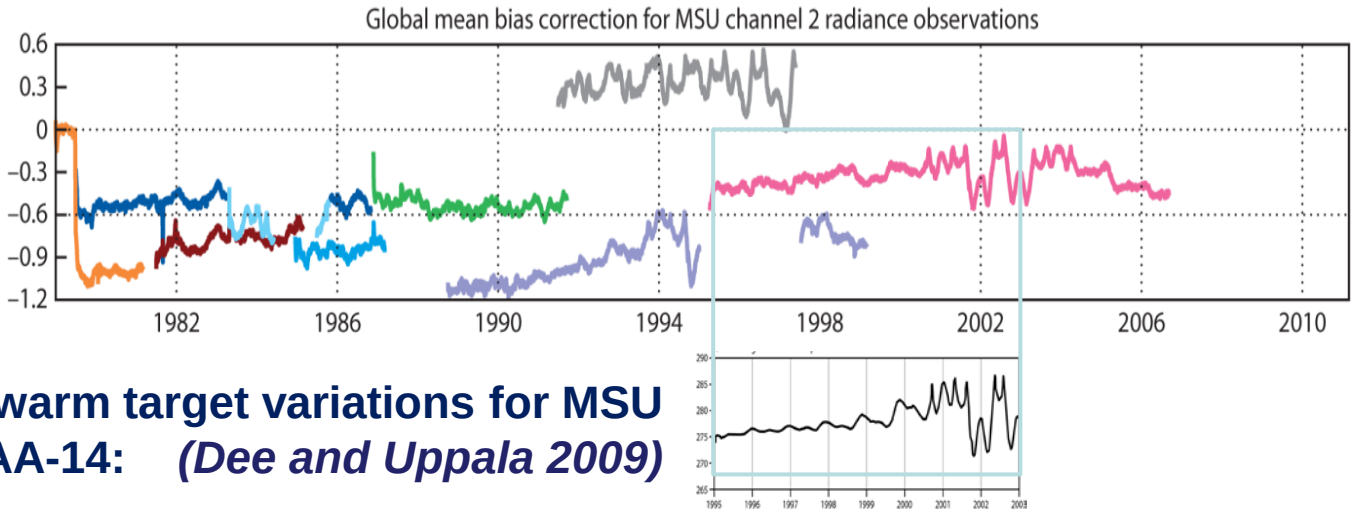
Systematic errors *(instrument calibration, spectroscopy in radiative transfer models, …)* are expressed in terms of global predictors

The bias parameters are included in the variational control:

$$\mathbf{J}(\mathbf{x},\beta) = (\mathbf{x}_b - \mathbf{x})^T \mathbf{B}^{-1} (\mathbf{x}_b - \mathbf{x}) + \left[\mathbf{y} - \mathbf{h}(\mathbf{x},\beta)\right]^T \mathbf{R}^{-1} \left[\mathbf{y} - \mathbf{h}(\mathbf{x},\beta)\right]$$



On-board warm target variations for MSU NOAA-14: ***(Dee and Uppala 2009)***

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CM-SAF SSM/I: Level 1b Brightness Temperature

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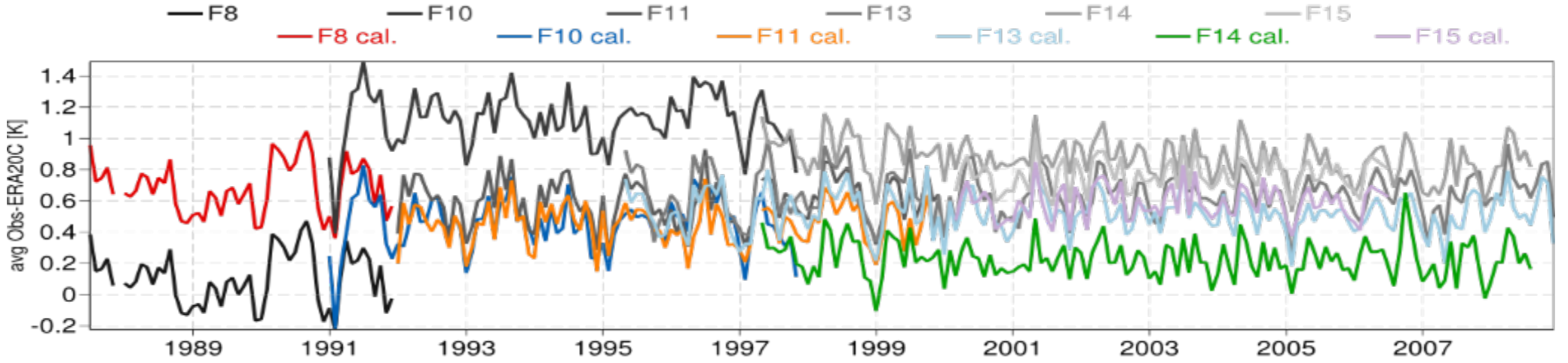
- ✓ Data covering the 1987-2009 period reprocessed by CM-SAF Improvements in the reprocessed version includes a better calibration, recovery of extra-data, better knowledge of instrument characteristics
- ✓ Prior to assimilation in ERA5, the data have been compared to off-line RTTOV simulations using interpolated fields from ERA-Interim and ERA-20C.

Mean departure SSM/I-ERA20C in Ch4 (37H), Ocean, ice-free and non-rainy scenes, with/without inter-calibration offsets



Differences between grey and colour curves show impact of application of CM-SAF brightness temperature inter-calibration offset

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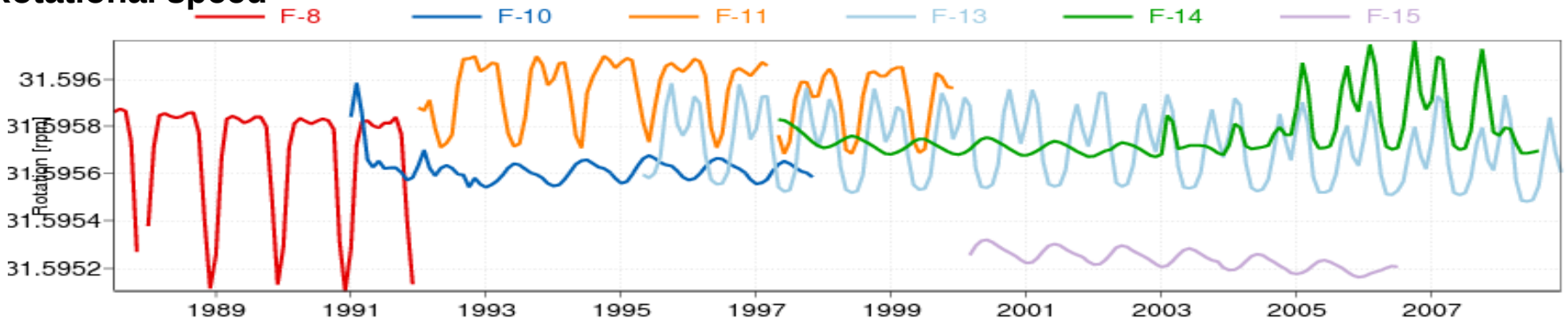
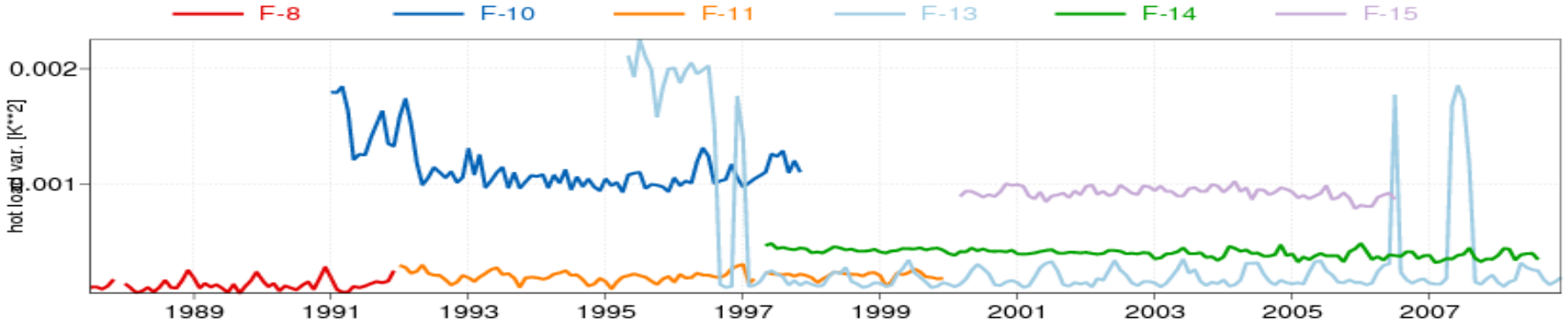
Rotational speed



Variance of the hot load reading



Improvements in satellite radiance simulation

	ERA-Interim	ERA5
Radiative transfer model	RTTOV-7	RTTOV-11
CO2 (for IR radiances SSU and HIRS)	Fixed	**Evolving CO2** (CMIP5 trends + MACC lat-press variations
Rainy SSM/I Radiances(Microwave Imagers)	1D+4D VAR	4DVAR
All-sky Assimilation	Clear-Sky Assimilation except 1D+4DVar SSM/I	All-sky for: all microwave imaging and WV sounding channels and some overcast infrared channels
Response-functions:		
- SSU cell pressure	Fixed cell-pressure	cell-pressures corrected (Saunders et al. 2013)
- HIRS	- Standard	Shifted spectral response functions for NOAA-11 and -14 (Chen et al. 2013)
- Other satellites	As in operational 31r2	As in operational 41r2

Evolving CO2 in RTTOV

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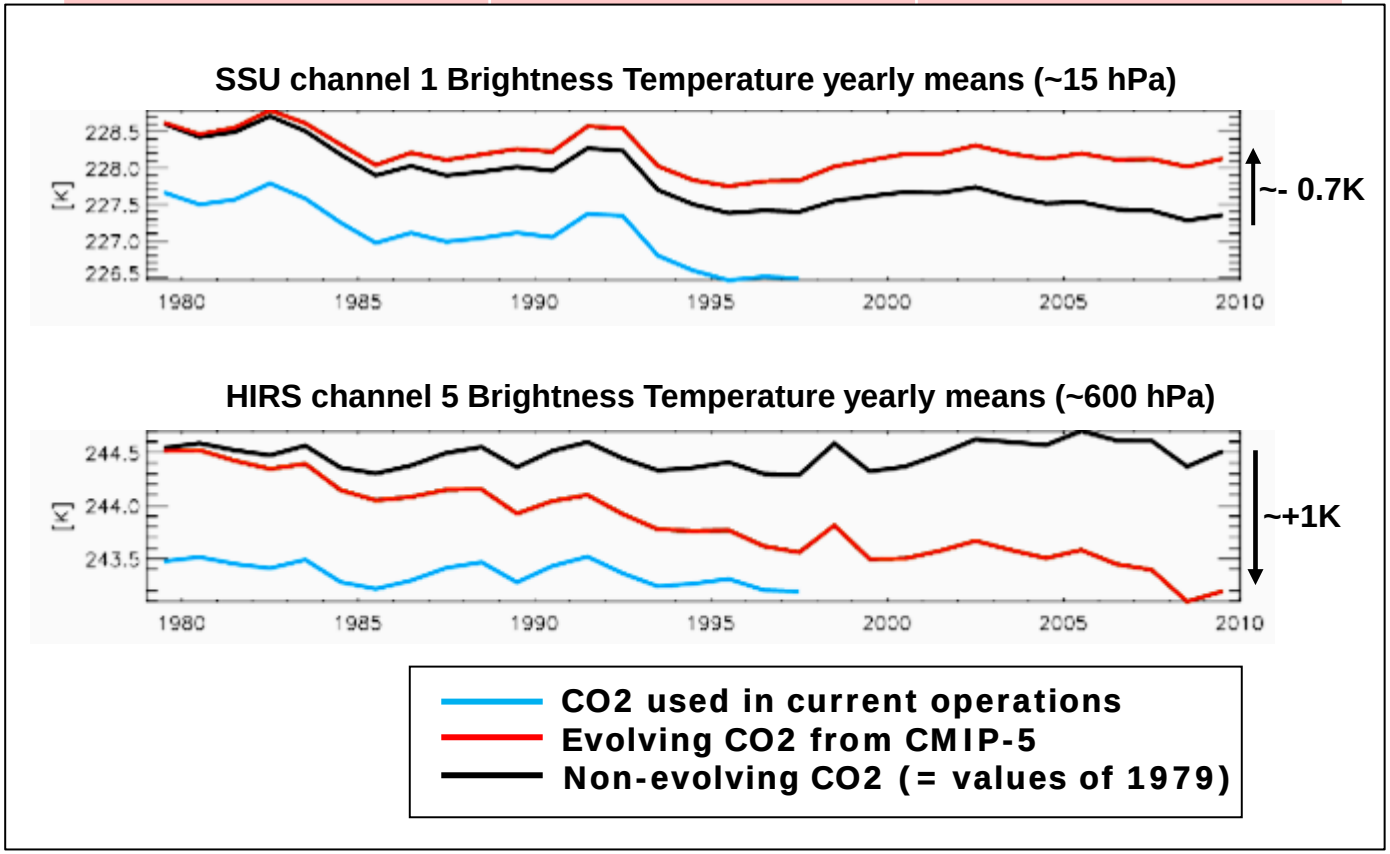
	ERA-Interim	ERA5
Radiative transfer model	RTTOV-7	RTTOV-11
CO2 (for IR radiances SSU and HIRS)	**Fixed**	**Evolving CO2 (CMIP5 trends + MACC lat-press variations**



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New: the ERA5 Observation Feedback Archive (OFA)

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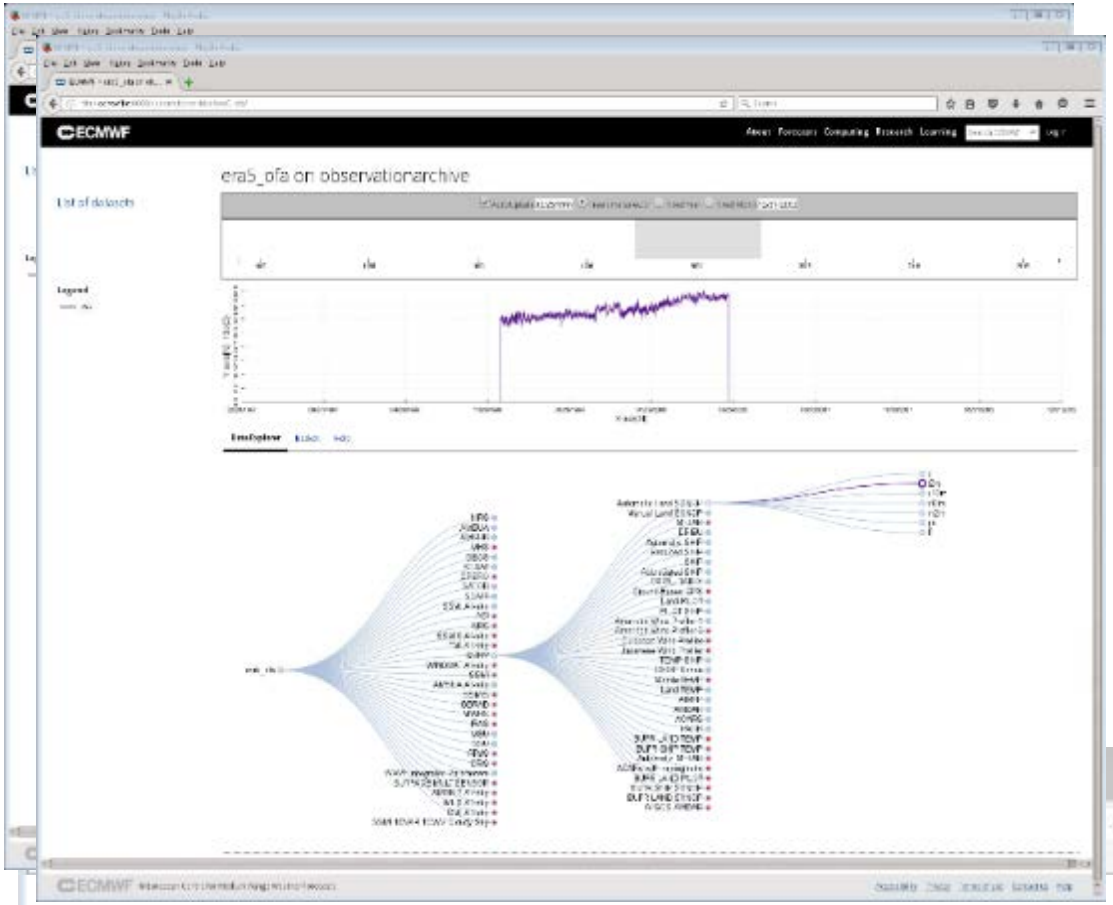

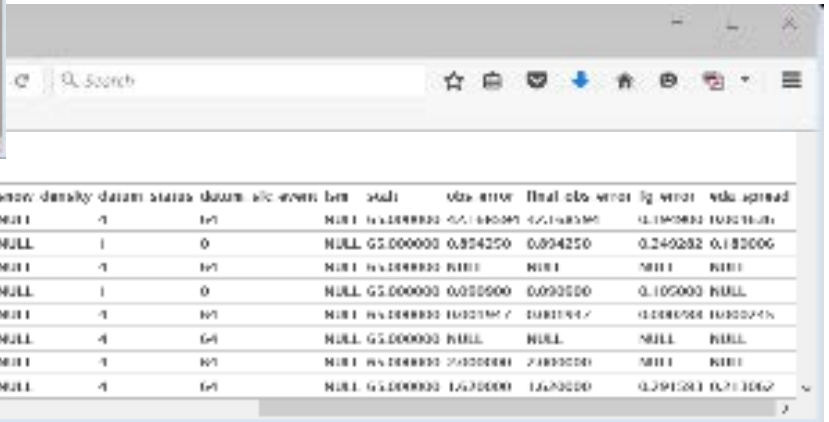

Gionata Biavata

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Survey historical satellite data for potential usage in reanalysis
Met Office, ECMWF

European Commission

By Roger Saunders and Paul Poli

Covering 190 satellite datasets:

Observation operators:

- ✓ RTTOV coefficients have been updated for a number of old satellite sensors (MetOffice).

Instrument	Characteristics	Immediate concern	Recommendation
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

Selection of old instruments with significant potential to improve the reanalysis record

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ERA CLIM

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Concluding remarks

ECMWF has a long experience with reanalysis

The quality is to a large extent determined by satellite data

- Mostly using level 1b data; plus usage of an observation operator in the assimilation system

Although variational bias correction can counteract on (inter-satellite) biases:

- It relies on redundancy, anchors and non-biased model
- Therefore, nothing beats a homogeneous and well inter-calibrated data record.
- Reanalysis observation feedback information may facilitate the realization of such data sets
- Meta data is important to allow for, e.g., cross checks on bias estimates

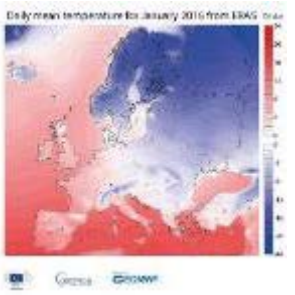
(Backward) extension of the historical satellite record is very valuable to reanalysis

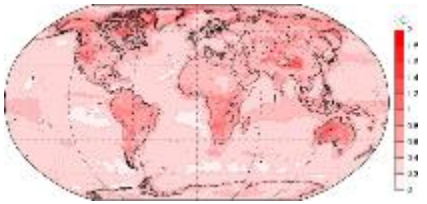
ERA5 two-months test data set is publicly available

- *https://climate.copernicus.eu/climate-reanalysis*

2010-2016 stream to be released in Q1 2017, 1979-NRT end 2017

To be freely available: both gridded data and ***observation feedback*** (OFA).





Temperature ensemble Spread