The Use of Satellite Radiances in the ERA5 Reanalysis

Climate Change

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Overview

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- Background – the ERA5 Reanalysis
- Radiance Assimilation in ERA5
  - Reprocessed datasets (*e.g.* CMSAF SSMI)
  - Improved forward modelling (*e.g.* time varying CO_2)
  - Early-era sounding data (VTPR, 1972-79)
- Concluding remarks

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Reanalyses Produced at ECMWF

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

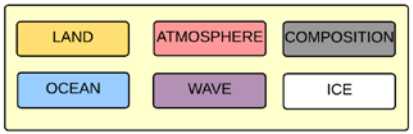
Centennial *Coupled*

2013 - 2015 ERA-20CM/20C	2016 CERA-20C	2017 CERA-SAT

Enhanced land

2012 ERA-Int/Land	2014 ERA-20C/Land	ERA5L

Towards a coupled earth system



Atmospheric composition

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

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What's new in ERA5?

	ERA-Interim	ERA5
Period	1979 – present	Initially 1979 – present, later addition 1950-1978
Streams	1979-1989, 1989-present	Parallel streams, one/two per decade
Assimilation system	2006, 4D-Var	2016 ECMWF model cycle (41r2), 4D-Var
Model input (radiation and surface)	As in operations, *(inconsistent sea surface temperature)*	***Appropriate for climate***, e.g., Evolution of 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 ***4D-Var ensemble*** at 62 km
Land Component	79km	ERA5L, 9km (separate, forced by ERA5)
Output frequency	6-hourly Analysis fields	***Hourly*** (three-hourly for the ensemble), ***Extended list of parameters*** ***~ 9 Peta Byte (1950 - timely updates)***
Extra Observations	Mostly ERA-40, GTS	Various ***reprocessed CDRs***, ***latest instruments***
Variational Bias correction	Satellite radiances, radiosondes predetermined	Also ozone, aircraft, surface pressure, newly predetermined for radiosondes.

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ERA5 - status

As part of C3S, the production of ERA5 is well underway:

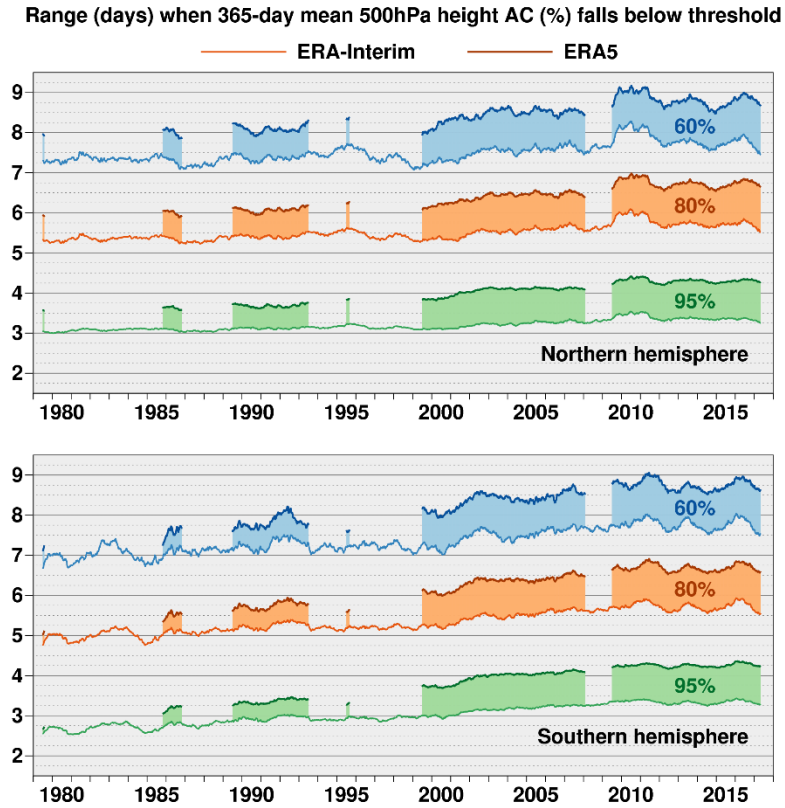
- Higher resolution, hourly output, uncertainty estimate.
- Produced in parallel streams
- Public Release 2010-2016 end June 2017
- Release other stream to be done in stages within Climate Data Store from 2018.

The performance of ERA5 is very promising in the troposphere.

- improved global hydrological and mass balance
- reduced biases in precipitation,
- refinement of the variability and trends of surface air temperature.

There are some imperfections, though

- Stratospheric temperature biases
- Initially there were quality issues over the southern hemisphere in the 1980s (delay in production stream)



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Reprocessed radiances: CM-SAF SSM/I

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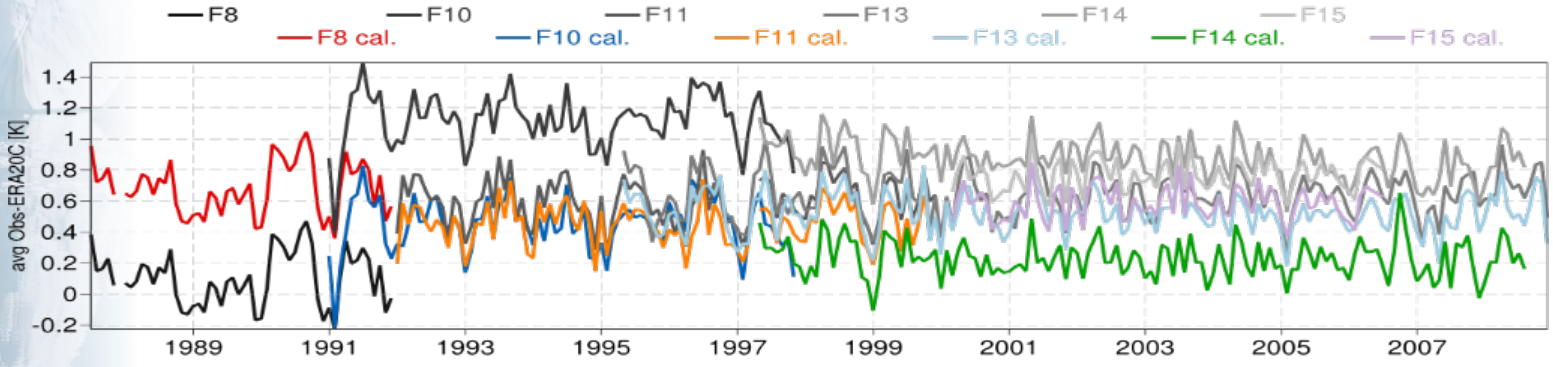
- ✓ **SSM/I data covering the 1987-2009 period reprocessed by CM-SAF: better calibration, recovery of extra-data, & better knowledge of instrument characteristics**
- ✓ **Prior to assimilation in ERA5, the data have been compared to off-line RTTOV simulations using interpolated fields from ERA-Interim 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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ERA5- Improvements in forward model

	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
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

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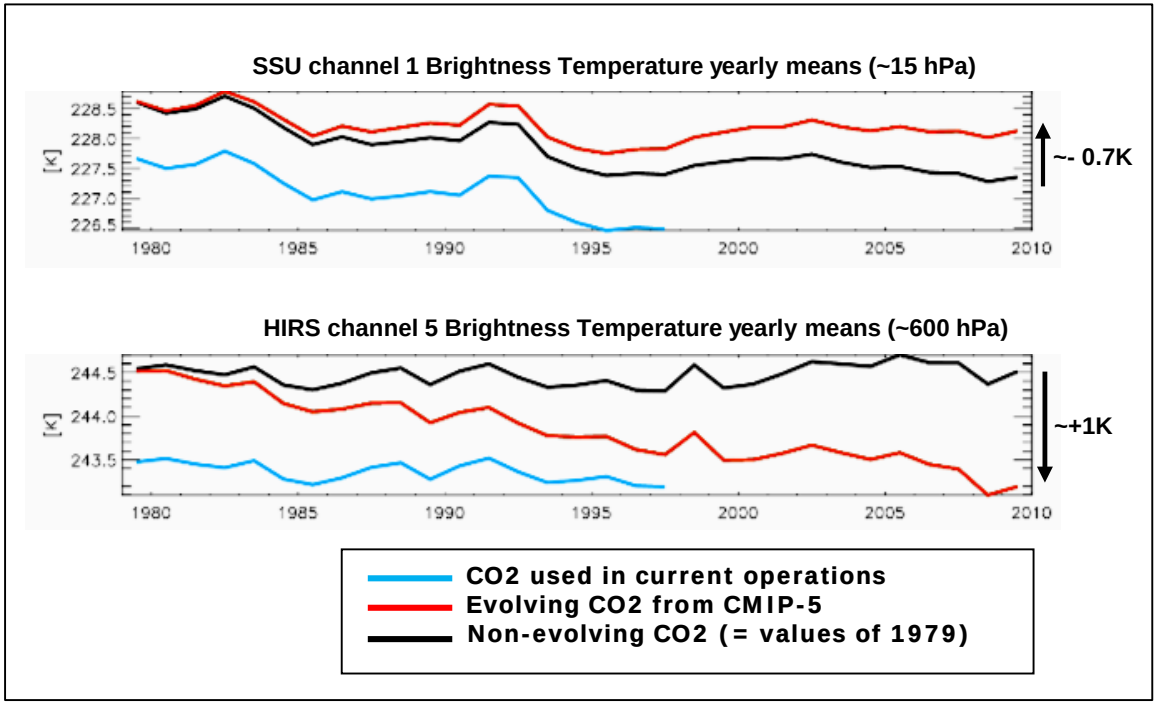
ERA5 - Accounting for changing CO_2

Simulated brightness temperatures



Vertical Temperature Profiling Radiometer

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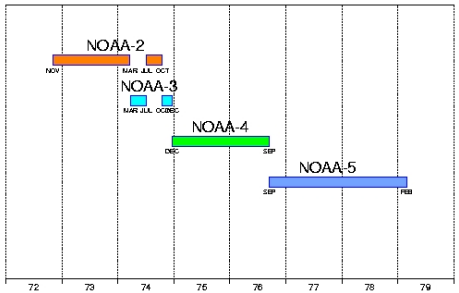
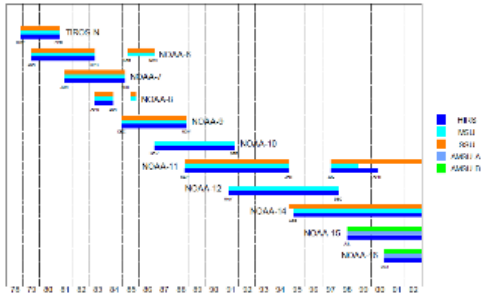
	VTPR (McMillin et al. 1973)	HIRS/2 (Schwalb 1978)
Inclination	101.7° (sun-synchronous)	98.9° (sun-synchronous)
Satellite altitude	1,464 (1,510) km	870 (833) km
Horizontal resolution	(nadir) 55 x 57 km (scan edge) 67 x 91 km	(nadir) 17.4 x 17.4 km (scan edge) 29.9 x 58.5 km
Scan angle	±30.3°	±49.5°
Swath	1,876 km	2,240 km
#FOV	23	56
#Instrument	Two / satellite	One / satellite





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VTPR Channel specifications

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NOAA 2/VTPR Set 1

Ch	Center wavenumber (cm^{-1})	Absorption band	Half-width (cm^{-1})
1	667.50	15μ CO_2	3.6
2	677.40	15μ CO_2	11.1
3	694.95	15μ CO_2	12.4
4	708.25	15μ CO_2	10.7
5	725.35	15μ CO_2	11.4
6	747.40	15μ CO_2	12.0
8	835.75	Window	7.1
7	533.65	18μ H_2O	15.3

McMillin et al. (1973)

NOAA 6/HIRS/2

Ch	Center wavenumber (cm^{-1})	Absorption band	Half-width (cm^{-1})
1	668.02	15μ CO_2	3
2	679.94	15μ CO_2	10
3	690.44	15μ CO_2	12
4	704.69	15μ CO_2	16
5	717.43	15μ CO_2	16
6	732.47	15μ CO_2	16
7	748.48	15μ CO_2	16
8	900.64	Window	35
9	1029.48	O_3	25
10	1217.77	6.3H_2O	60
11	1368.05	6.3H_2O	40
12	1485.76	6.3H_2O	80
13	2190.60	4.3μ CO_2	23
14	2210.09	4.3μ CO_2	23
15	2237.76	4.3μ CO_2	23
16	2269.43	4.3μ CO_2	23
17	2360.42	4.3μ CO_2	23
18	2514.97	Window	35
19	2654.58	Window	100
20	14453.14	Visible	1000

Kidwell (ed) (1998)

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Preparation for assimilating VTPR in ERA5

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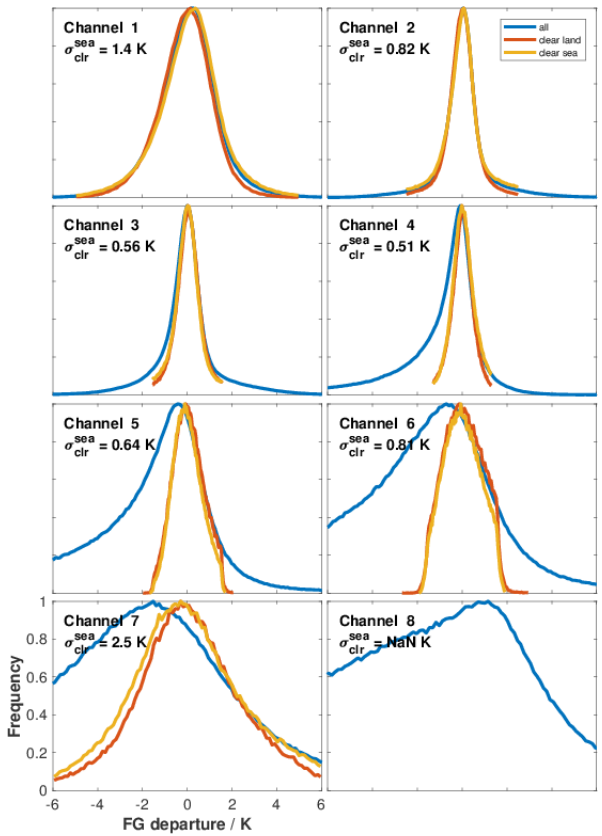
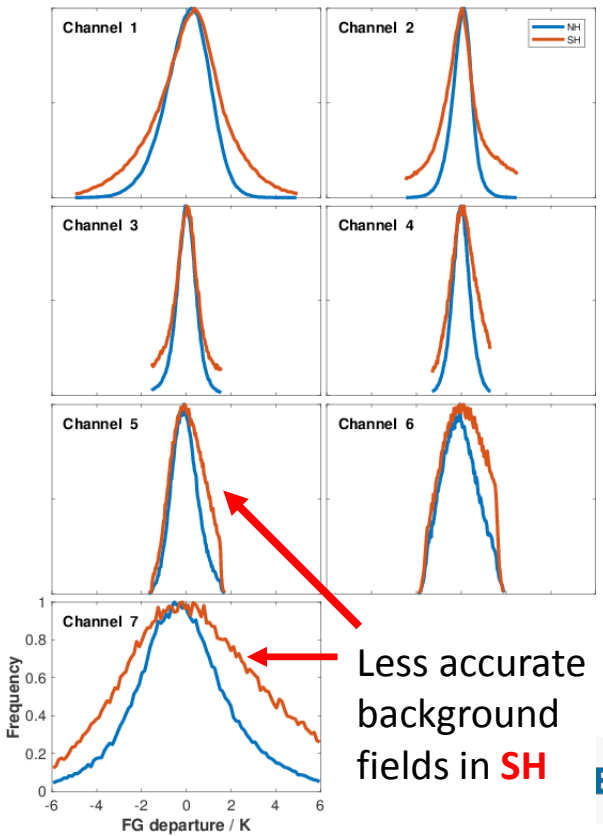
VTPR first guess departures for May 1978.



VTPR first guess departures For **NH** and **SH.**



Less accurate background fields in **SH**

- Builds on experience gained in ERA-40 and JRA-55
- VarBC (4 thicknesses, constant, 3 scan angle predictors)
- Cloud detection based on HIRS scheme at ECMWF (Krzeminski, 2009)
- Remaining challenges: channel selection, **R** tuning, **B** for 1972-1979
- Expect 1970s stream(s) to start mid-2018.

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Concluding remarks

- The ERA5 reanalysis is currently in production (1979-present) - performance is significantly improved *wrt* ERA-Interim.
- ERA5 uses a 2016 ECMWF model cycle (41R2) & benefits from a range of upgrades in the use of satellite data implemented over the last 10 years.
- Early streams (1950 - 1979) are due to start in 2018, and complete by end-2018. They present some challenges, *e.g.*: optimisation of **B**, and optimising the use of early radiance datasets (*e.g.* VTPR).
- ERA5 benefits from a number of reprocessed satellite datasets (*e.g.* CM-SAF SSMI) and other innovations in forward models, as will future reanalyses.

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