

The Use of Satellite Radiances in the ERA5 Reanalysis



Climate Change

Bill Bell,

Paul Berrisford, Gionata Biavati, Per Dahlgren, Dick Dee, Rossana Dragani, Manuel Fuentes, Hans Hersbach, András Horanyi, Joaquín Muñoz-Sabater, Carole Peubey, Raluca Radu, Iryna Rozum, Dinand Schepers, Adrian Simmons, Cornel Soci, Jean-Noël Thépaut and Sebastien Villaume.

European Centre for Medium-Range Weather Forecasts





Climate
Change

Overview

- Background – the ERA5 Reanalysis
- Radiance Assimilation in ERA5
 - Reprocessed datasets (*e.g.* CMSAF SSMI)
 - Improved forward modelling (*e.g.* time varying CO₂)
 - Early-era sounding data (VTPR, 1972-79)
- Concluding remarks



Climate
Change

Reanalyses Produced at ECMWF

Atmosphere/land

1) 1979 - 1981
FGGE

2) 1994 - 1996
ERA-15

3) 2001 - 2003
ERA-40

4) 2006 - ...
ERA-Interim



5) 2016 - ...
ERA5

including ocean waves

Ocean

2006
ORAS3

2010 - ...
ORAS4

2016 - ...
ORAS5

including sea ice



Centennial

2013 - 2015
ERA-20CM/20C

2016
CERA-20C

2017
CERA-SAT

Coupled

Enhanced land

2012
ERA-Int/Land

2014
ERA-20C/Land

Copernicus
Europe's eyes on Earth
ERA5L

Atmospheric composition

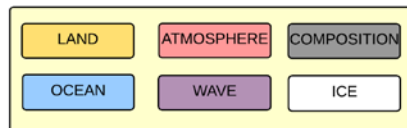
2008 - 2009
GEMS

2010 - 2011
MACC



2017 - ...
CAMs

Towards a coupled earth system





Climate
Change

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, (<i>inconsistent sea surface temperature</i>)	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.



Climate
Change

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.

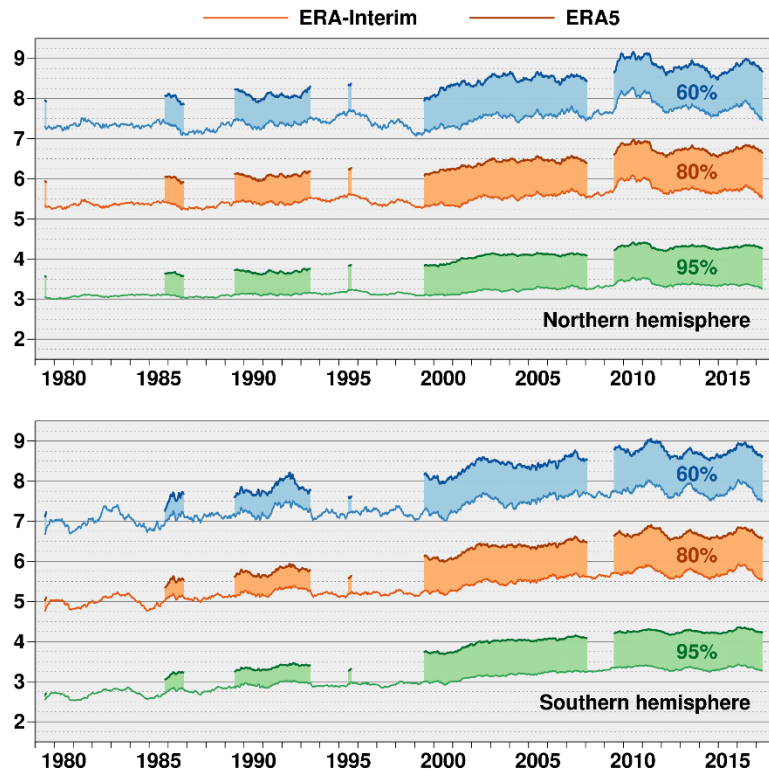
The performance of ERA5 is very promising in the troposphere.

- 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)

Range (days) when 365-day mean 500hPa height AC (%) falls below threshold



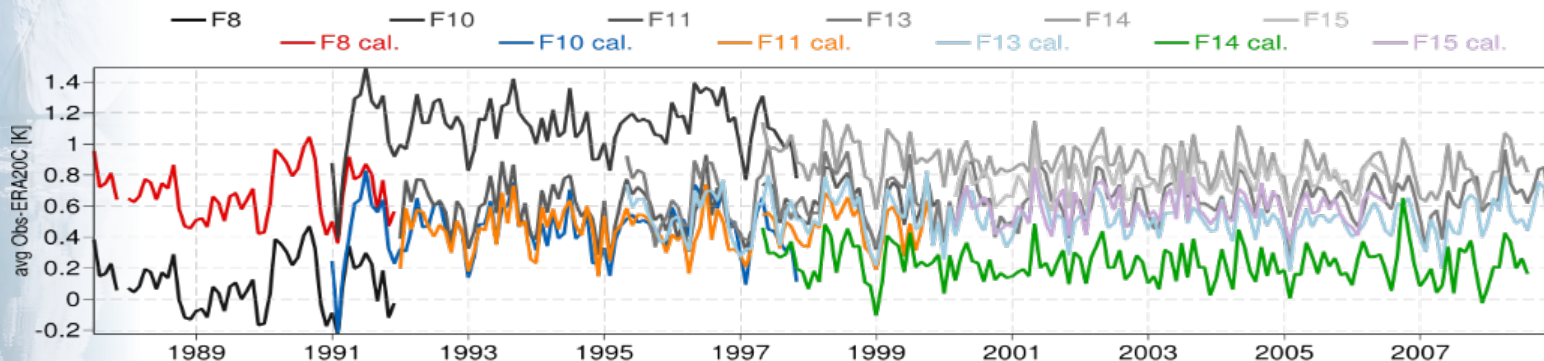


Climate
Change

Reprocessed radiances: CM-SAF SSM/I

- ✓ 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



Climate
Change

ERA5 - Improvements in forward model

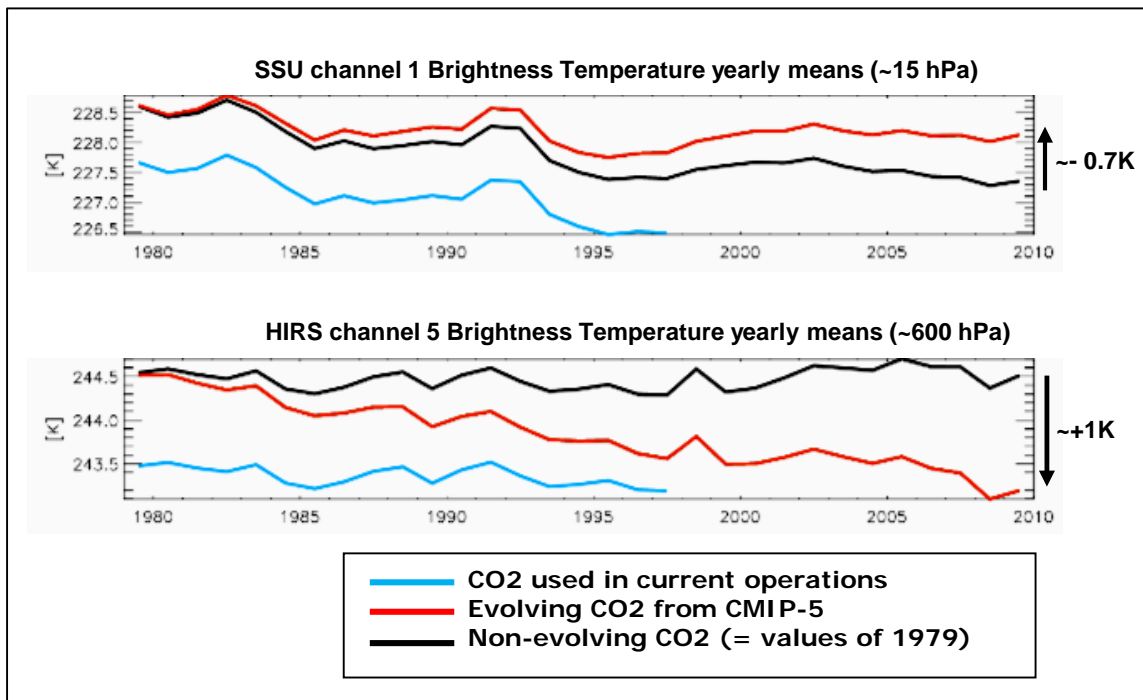
	ERA-Interim	ERA5
<i>Radiative transfer model</i>	RTTOV-7	RTTOV-11
<i>CO2 (for IR radiances SSU and HIRS)</i>	Fixed	Evolving CO2 (CMIP5 trends + MACC lat-press variations)
<i>Rainy SSM/I Radiances(Microwave Imagers)</i>	1D+4D VAR	4DVAR
<i>All-sky Assimilation</i>	Clear-Sky Assimilation except 1D+4DVar SSM/I	All-sky for: all microwave imaging and WV sounding channels
<u><i>Response-functions:</i></u>		
- 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



Climate
Change

ERA5 - Accounting for changing CO₂

Simulated brightness temperatures

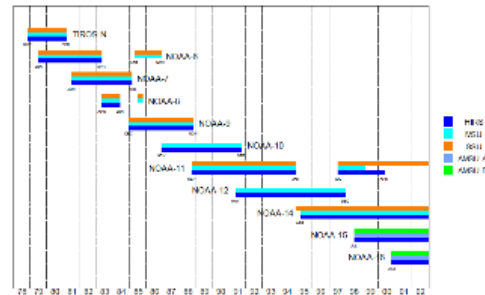
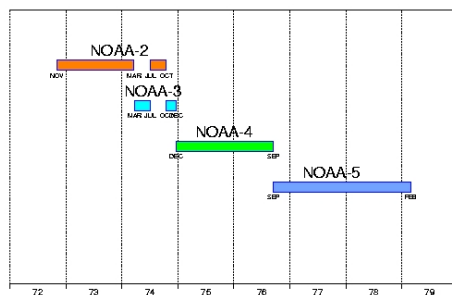




Climate
Change

Vertical Temperature Profiling Radiometer

	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	$\pm 30.3^\circ$	$\pm 49.5^\circ$
Swath	1,876 km	2,240 km
#FOV	23	56
#Instrument	Two / satellite	One / satellite



Shinya Kobayashi



Climate
Change

VTPR Channel specifications

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 ₂ O	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 ₂ O	60
11	1368.05	6.3H ₂ O	40
12	1485.76	6.3H ₂ O	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)

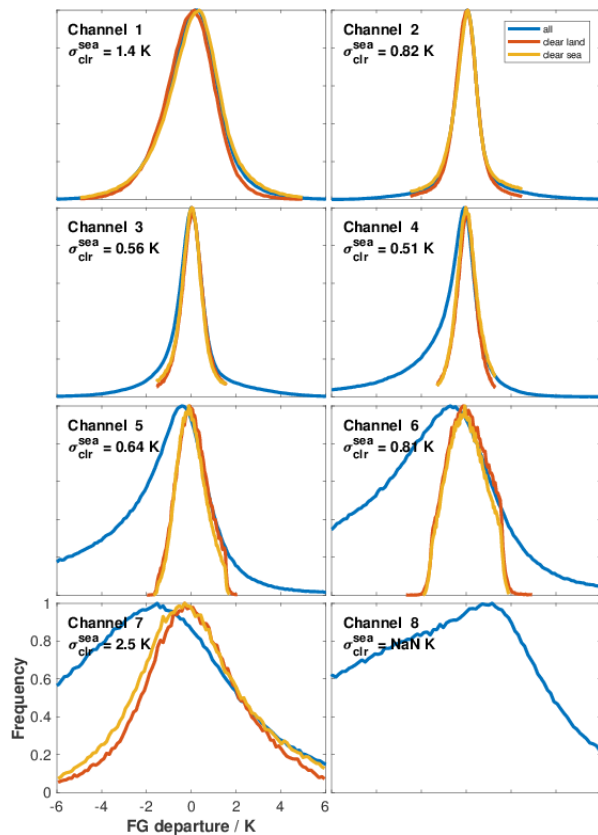
Shinya Kobayashi



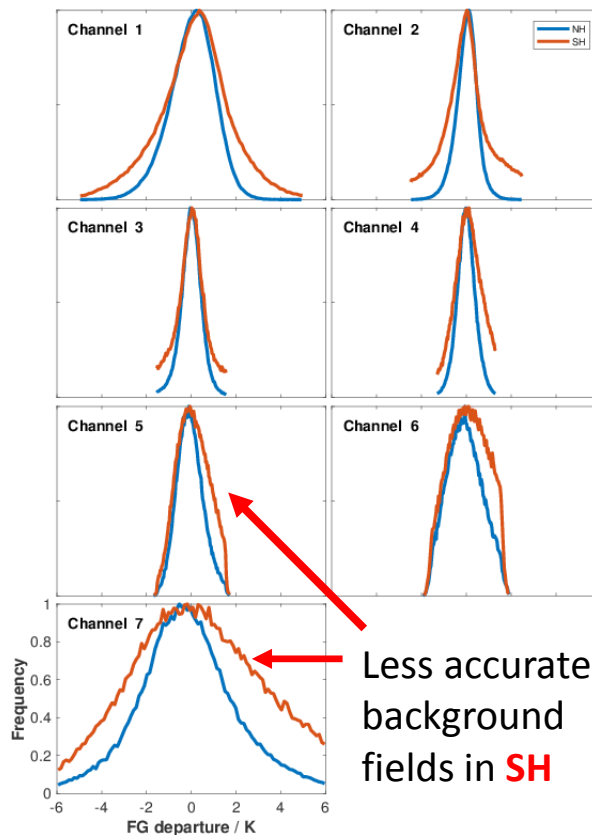
Climate
Change

Preparation for assimilating VTPR in ERA5

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.



Climate
Change

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.