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C3S global reanalysis: integrator of climate observations; status and requirements for the observing system

Hans Hersbach,

Bill Bell, Paul Poli, Paul Berrisford, Andras Horanyi, Julien Nicolas, Raluca Radu, Joaquin Munoz Sabater, Cornel Soci, Dinand Schepers, Adrian Simmons, Carlo Buontempo and Jean-Noel Thepaut.

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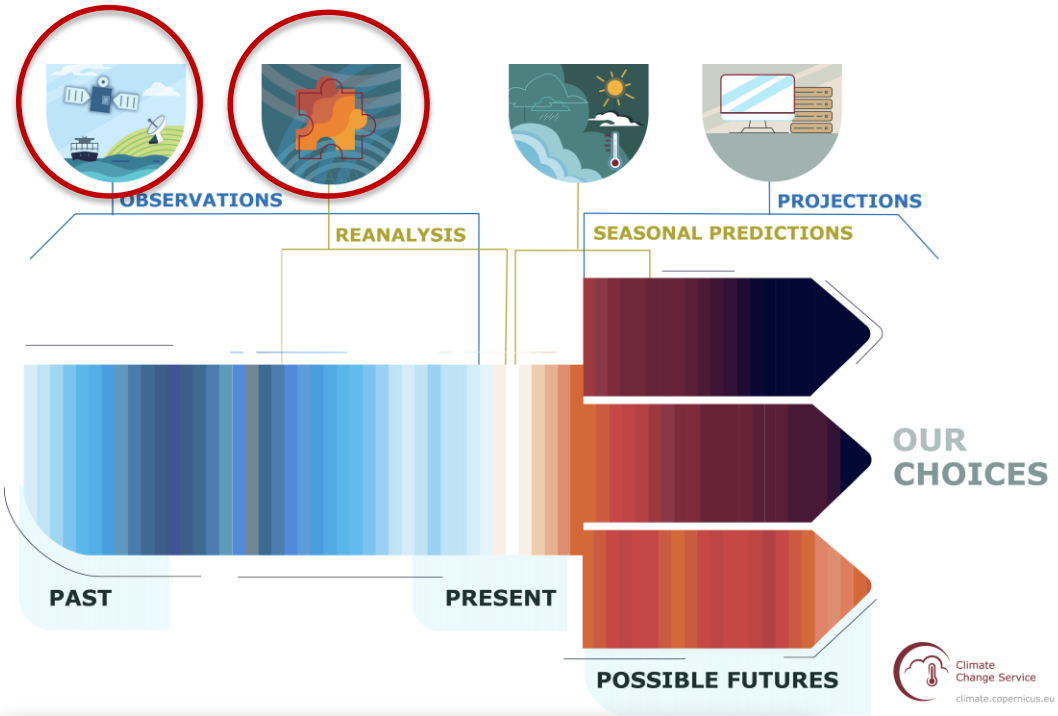
C3S and the Climate Data Store

ECMWF operates the Copernicus Climate Change Service (C3S) and Copernicus Atmosphere Monitoring Service (CAMS) on behalf of the European Commission.



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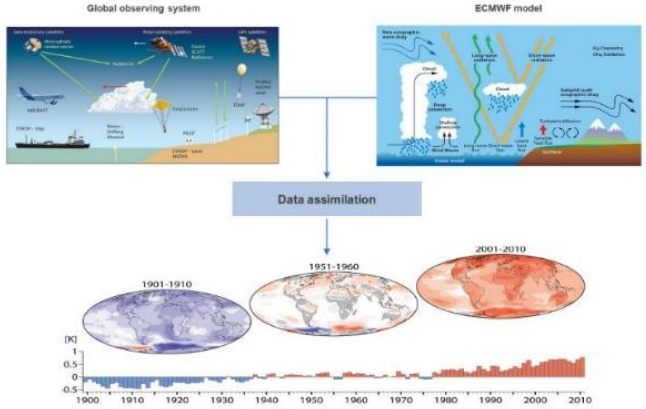
What is reanalysis and why is it important

Reconstruction of the past weather & climate:

- ✓ **Input:** integrator of all available observations (level 1B, 2), some of them as forcing (level 4)
- ✓ Deal with inhomogeneities, relative biases, data formats, range of observables
- ✓ **Output:** convenient and as accurate as possible 'maps without gaps' of 3D atmosphere (+ other domains)

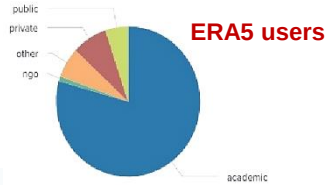


State-of-the-art:

- ✓ Redo historical weather using a modern but fixed NWP system
- ✓ For extended period back in time, but at lower resolution
- ✓ Maintained close to NRT
- ✓ Made available to users in a convenient way

Multiple classes of applications:

- ✓ Study of **specific events** or phenomena:
  - accurate (3D) synoptic situation; i.e., **the weather of the day**
- ✓ **Climate monitoring:**
  - Accurate recent synoptic situation + **consistent 30-year climate**
- ✓ **Climate** applications:
  - low-frequency variability of **the mean state**
  - Statistics, e.g., of extremes



ERA5 users

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Status of the ERA5 global reanalysis

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Full-observing-system global reanalysis for the atmosphere, land surface and ocean waves

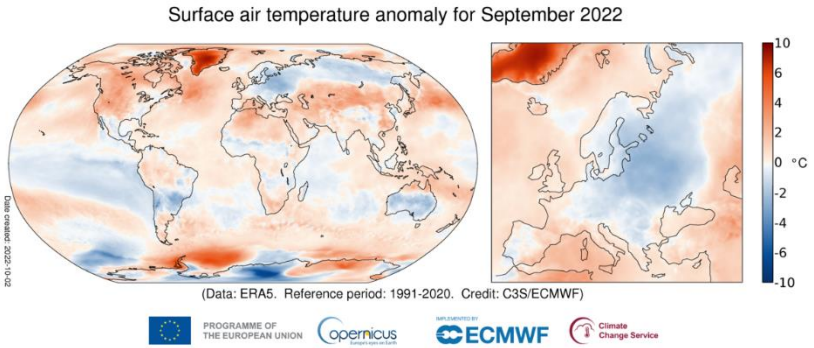
- Produced at ECMWF, by the **Copernicus Climate Change Service**
- >92,000 users, >500 Tbyte of downloads per week

- From **1959** (now extended back to **1940**, data release coming)
- **Continues** into the present, daily updates **5 days behind real time**
- **Hourly snapshots** at **31 km resolution** up to about 80 km height
- **Uncertainty estimate** from a 10-member ensemble at half resolution
- Total dataset about 12 petabyte

- **ERA5-Land**: Dynamically downscaled land product at **9km**. 1950 onwards

We have started preparations for ERA6

- At least 18 km, 70 years, start production in 2024
- Use more and better observations in a better way.



Observation usage:

- Over 100 billion so far

Usage of external (gridded) products 'as is':

- SST and sea-ice cover
- GHGs, aerosols, TSI, (diagnostic) ozone

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The ERA5 observing system

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53K (1950) – 26 Million (2021) obs per day
Over 200 types of reports

Satellite observations, mostly since 1979:

Microwave radiances:
- temperature and humidity sounders, imagers

Infrared sounder radiances
- multispectral, hyperspectral

Geostationary radiances
Atmospheric motion vectors
GNSS-RO bending angles
Scatterometer: ocean wind + land soil moisture
Ozone level 2 retrievals + level 1B
Altimeter wave height

Conventional observations

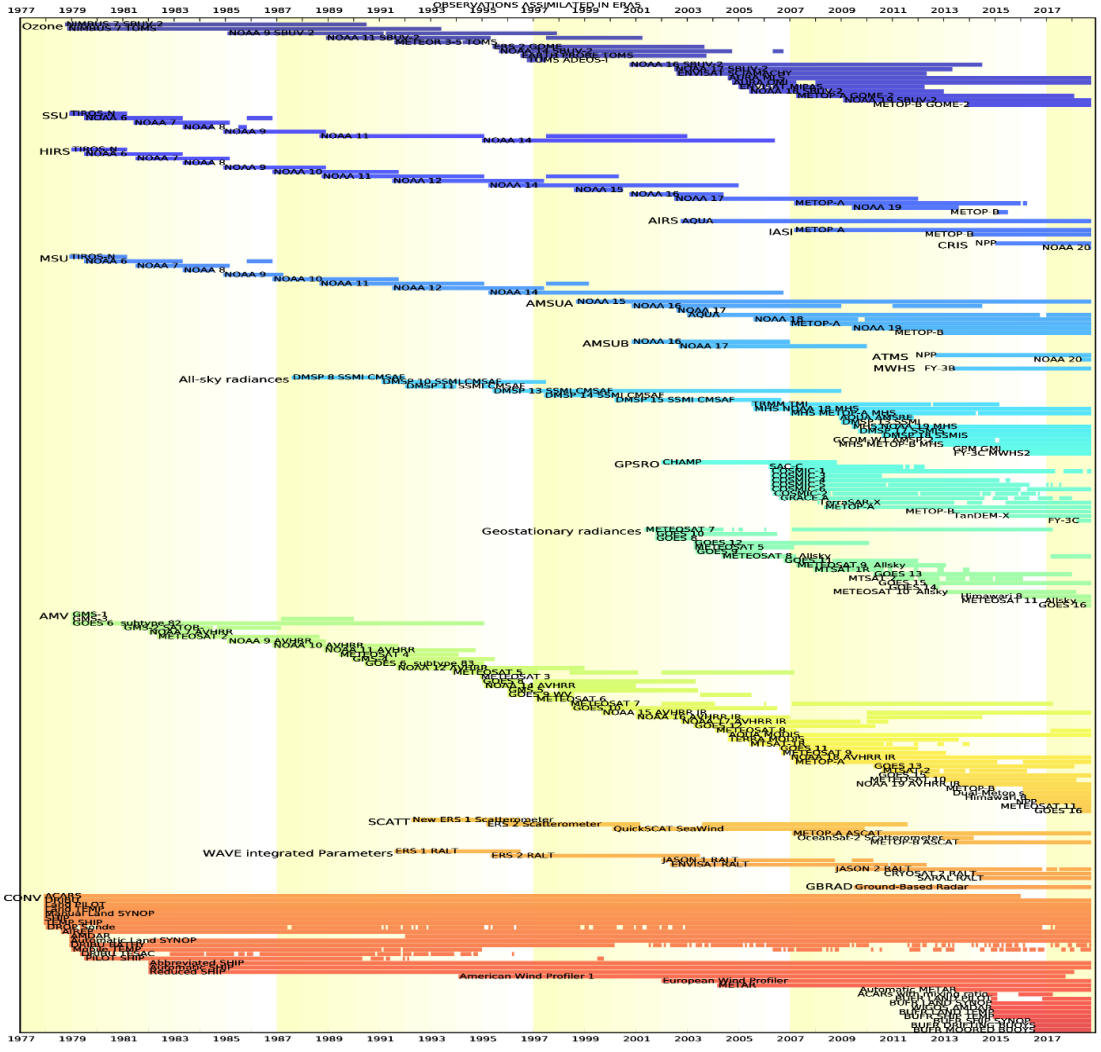
Surface: Land stations, buoys, ships
Upper-air: Balloons, dropsondes, aircraft, profilers

Latest instruments

TAMDAR, MODE-S, SPIRE, FY-3, ..

+ Reprocessed satellite observations

+ Rescued in situ observations



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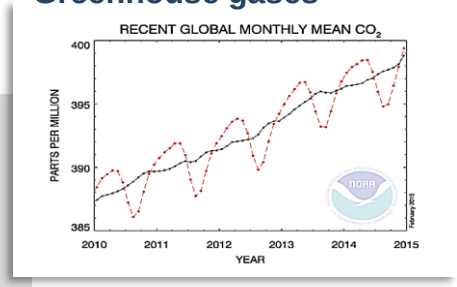
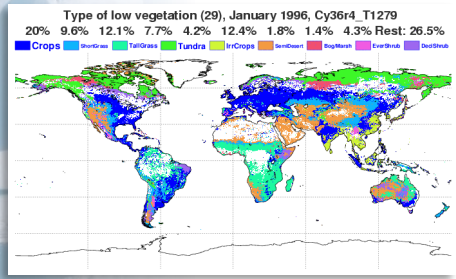
Observation-based (gridded) forcing and boundary conditions

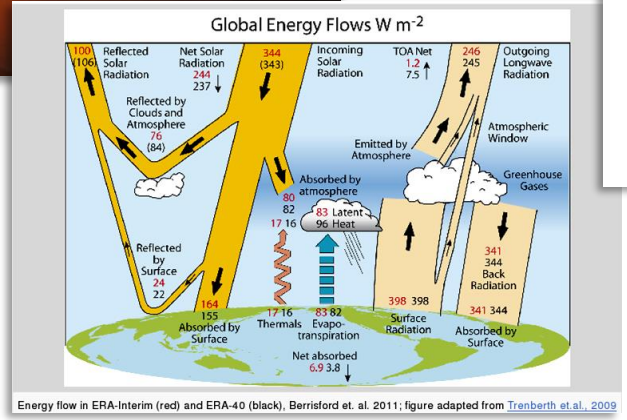
that reflect the 20th and 21th century evolution

Solar forcing

Greenhouse gases

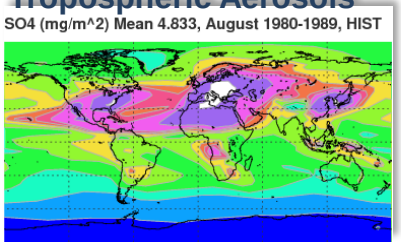




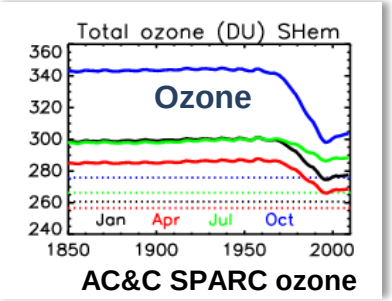


Energy flow in ERA-Interim (red) and ERA-40 (black), Berrisford et. al. 2011; figure adapted from Trenberth et.al., 2009

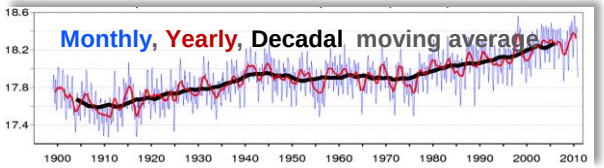
Tropospheric Aerosols



Volcanic eruptions



SST and sea ice



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In-situ: at the core of C3S & further collaborative activities; contractors NUIM, CNR, KNMI

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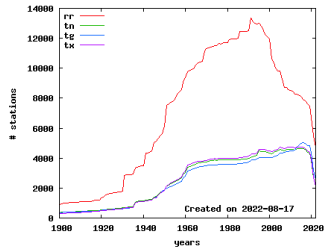
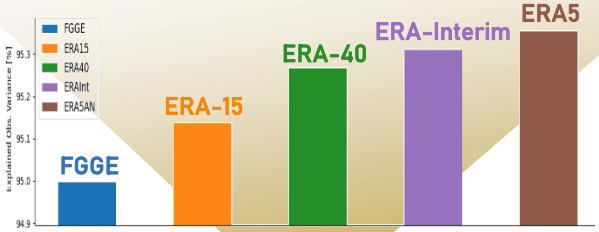
2. Organize data records into datasets, develop and apply data standards*. enrich collections with metadata*

(* with WMO)



Number of in-situ stations in E-OBS

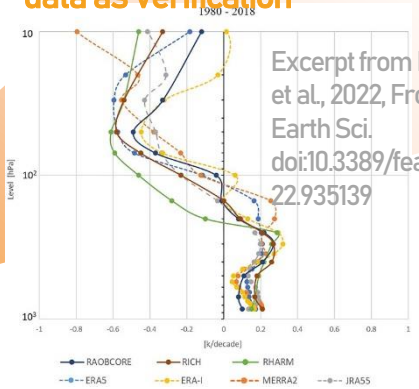
3. Assimilate data in global & high-resol. reanalyses



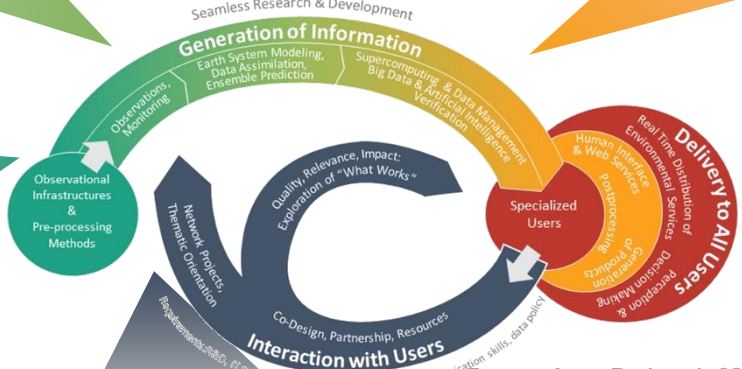
% explnd. var. in tropos. upper-air temp. obs. 1979/07/15

SCIENCE FOR SERVICES JOURNEY

4. Use reference data as verification

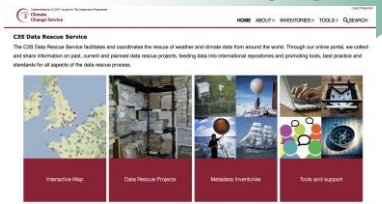


Excerpt from Essa et al., 2022, Front. Earth Sci. doi:10.3389/feart.2022.935139



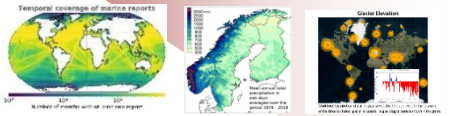
Excerpt from Ruti et al., 2020, Bull. Amer. Meteorolog. Soc. doi:10.1175/BAMS-D-17-0302.1

1. Acquire data records, rescue from decaying



Data rescue portal, working with WMO I-DARE and national partners

5. Serve datasets, collect user feedback



https://cds.climate.copernicus.eu/

>> Search for "in-situ"

6. Learn lessons, identify issues & gaps, refine uncertainty estimates prioritize data rescue, reprocess, ...

C3S Satellite data rescue and reprocessing; agreements with EUMETSAT and Spascia

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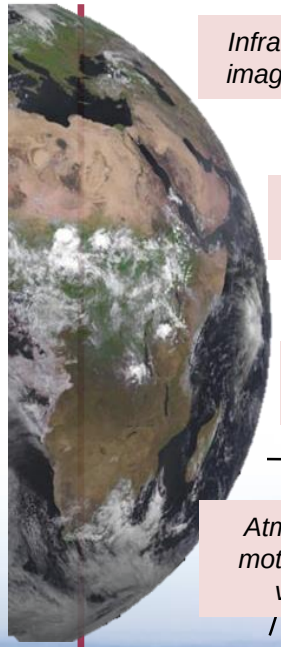

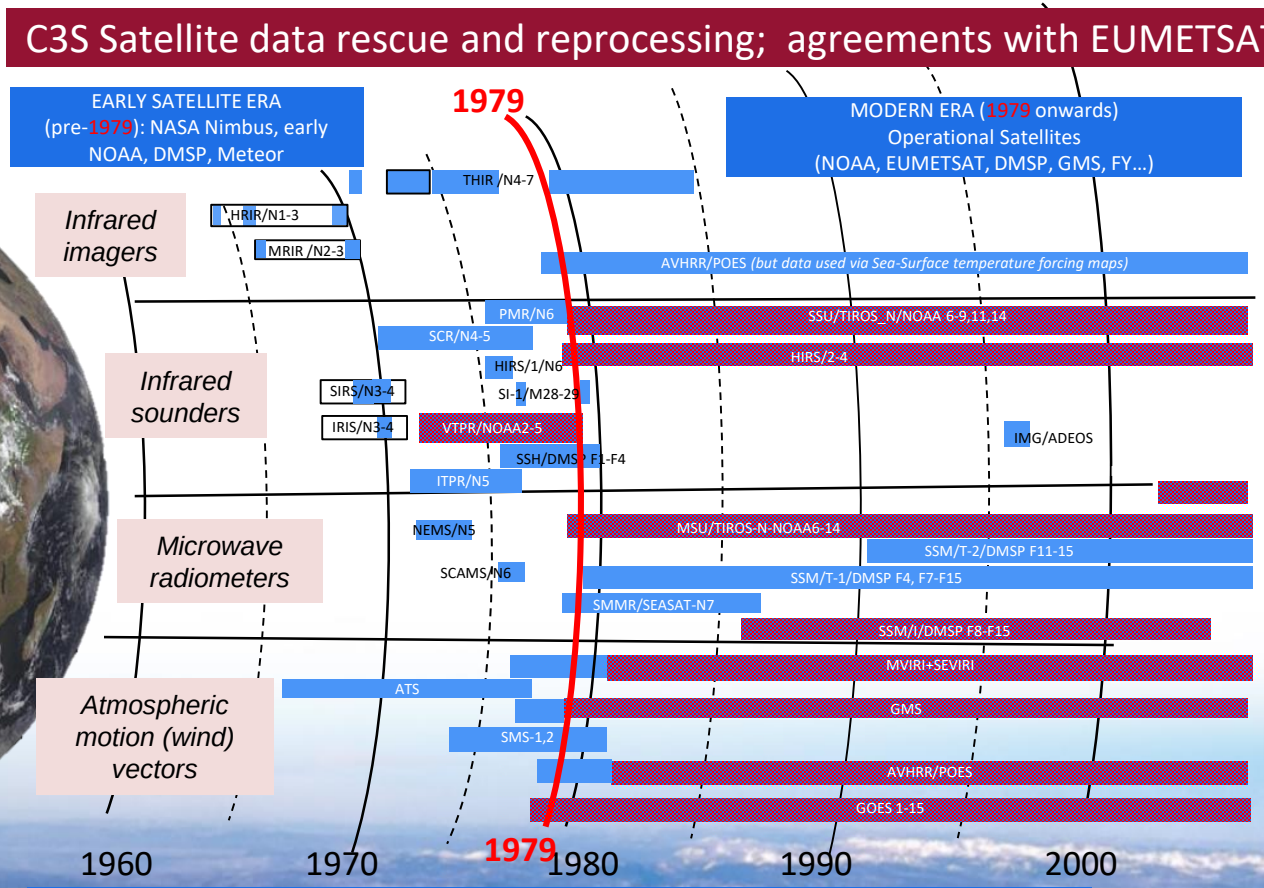

Recent progress includes :

- **Efficient collaboration** between rescue and reprocessing activities (*e.g.* Radiative transfer modelling, MSU reprocessing, polar AMVs from early rescued satellite radiances)
- **Assessment of COP1 datasets:** feedback from ECMWF in advance of ERA6, optimize processes to accelerate data readiness for ERA6
- **Inventory of early satellite data records:** intended for wider community use, discussed way forward towards publication

Data Rescue (Spascia, C3S2_314): decoding original data, reformatting, archiving & QC

Reprocessing (EUMETSAT, C3S2_310): recalibration, navigation, quality assessment

Both activities aim to improve assimilation readiness of these datasets for ERA6 and high-resolution (regional) reanalyses, and also support ECV production

Data not yet assimilated in ERA

Original or earlier-reprocessed data version assimilated in ERA5

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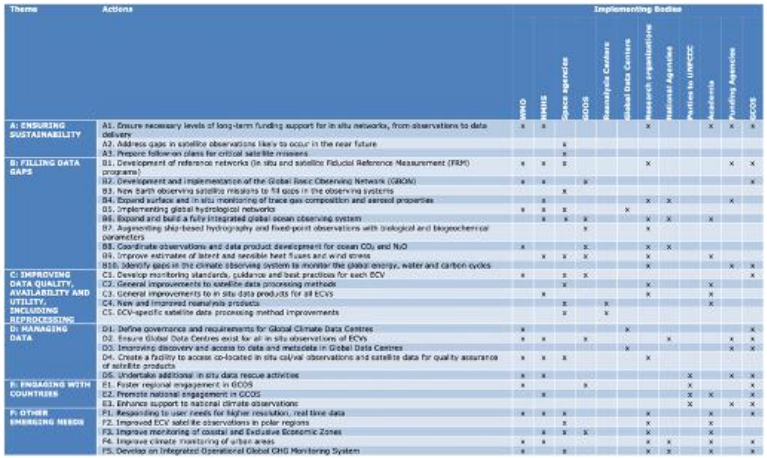
Final remarks

ERA5 contributes to GCOS IP action C4 (reanalysis)

- delivering 'maps without gaps' covering many variables of the climate system, continuing today



Theme	Actions	Implementing Bodies
A: ENSURING SUSTAINABILITY	A1. Ensure necessary levels of long-term funding support for in situ networks, from observations to data delivery	
	A2. Address gaps in satellite observations likely to occur in the near future	
	A3. Prepare follow-on plans for critical satellite missions	
B: FILLING DATA GAPS	B1. Development of reference networks (in situ and satellite Fiducial Reference Measurement (FRM) programs)	
	B2. Development and implementation of the Global Basic Observing Network (GBON)	
	B3. New Earth observing satellite missions to fill gaps in the observing systems	
	B4. Expand surface and in situ monitoring of trace gas composition and aerosol properties	
	B5. Implementing global hydrological networks	
	B6. Expand and build a fully integrated global ocean observing system	
	B7. Augmenting ship-based hydrography and fixed-point observations with biological and biogeochemical parameters	
	B8. Coordinate observations and data product development for ocean CO_2 and N_2O	
	B9. Improve estimates of latent and sensible heat fluxes and wind stress	
	B10. Identify gaps in the climate observing system to monitor the global energy, water and carbon cycles	
C: IMPROVING DATA QUALITY, AVAILABILITY AND UTILITY, INCLUDING REPROCESSING	C1. Develop monitoring standards, guidance and best practices for each ECV	
	C2. General improvements to satellite data processing methods	
	C3. General improvements to in situ data products for all ECVs	
	C4. New and improved reanalysis products	
	C5. ECV-specific satellite data processing method improvements	
D: MANAGING DATA	D1. Define governance and requirements for Global Climate Data Centres	
	D2. Ensure Global Data Centres exist for all in situ observations of ECVs	
	D3. Improving discovery and access to data and metadata in Global Data Centres	
	D4. Create a facility to access co-located in situ cal/val observations and satellite data for quality assurance of satellite products	
	D5. Undertake additional in situ data rescue activities	
E: ENGAGING WITH COUNTRIES	E1. Foster regional engagement in GCOS	
	E2. Promote national engagement in GCOS	
	E3. Enhance support to national climate observations	
F: OTHER EMERGING NEEDS	F1. Responding to user needs for higher resolution, real time data	
	F2. Improved ECV satellite observations in polar regions	
	F3. Improve monitoring of coastal and Exclusive Economic Zones	
	F4. Improve climate monitoring of urban areas	
	F5. Develop an Integrated Operational Global GHG Monitoring System	

but this leaves **room for improvement, e.g. :**

- consistent integration with more Earth-system components
- characterization of uncertainties (at various time-scales)
- improve incomplete historical datasets from comprehensive obs. networks and corresponding metadata
- scarcity of reference observations (even today) & metrological traceability …

Future reanalyses will all benefit from realization of GCOS IP actions

- in all 5 themes, <u>especially</u> those actions that will improve the <u>observational components</u>, in-situ and satellite, and <u>data records</u>' stewardship, quality, continuity, characterization, and availability

- C3S is already leading or participating in several other GCOS IP actions (e.g., C1-C5, D5, E3)

Recommendation: a clear call for support to all those that carry out GCOS IP actions

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