Solar channels assimilation and reanalysis at ECMWF: status, plans and challenges

Hans Hersbach, ECMWF

Thanks to: Angela Benedetti, Robin Hogan, Joaquin Munoz Sabater, Tim Stockdale and many others

Climate Change

In a nutshell

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When I started to work on reanalysis in 2011, I was baffled to learn how difficult it is to *exactly* know how much solar radiation reaches the Earth.

This talk lists potential benefits of the TRUTHS mission for ECMWF:

- ECV products directly derived from satellite observations
- Seasonal forecasting
- NWP
- Reanalysis

Key elements are:

- Accurate calibration of TSI and Earth radiation
  - Calibration of long-standing satellites (e.g., CERES)
  - Learn and improve on model errors
- Accurate measurements of the spectrum
  - Learn and improve on model errors
- Non availability in NRT
  - Complicates assimilation in NWP and reanalysis

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RMetS Royal Meteorological Society

ERA-20CM: a twentieth-century atmospheric model ensemble

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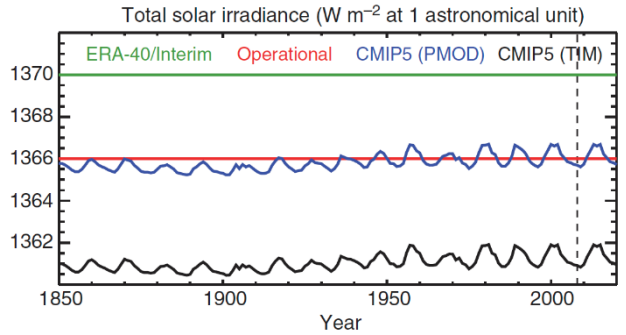

Figure 3. Total solar irradiance ($W m^{-2}$ at 1 Astronomical Unit) as used in ERA-40 and ERA-interim (green), the ECMWF operational model (red), CMIP5 PMOD (blue), and CMOD5 TIM (black) as used in ECMWF seasonal forecast system 4 and ERA-20CM.

ERA5 uses CMIP5 (Tim) scaling

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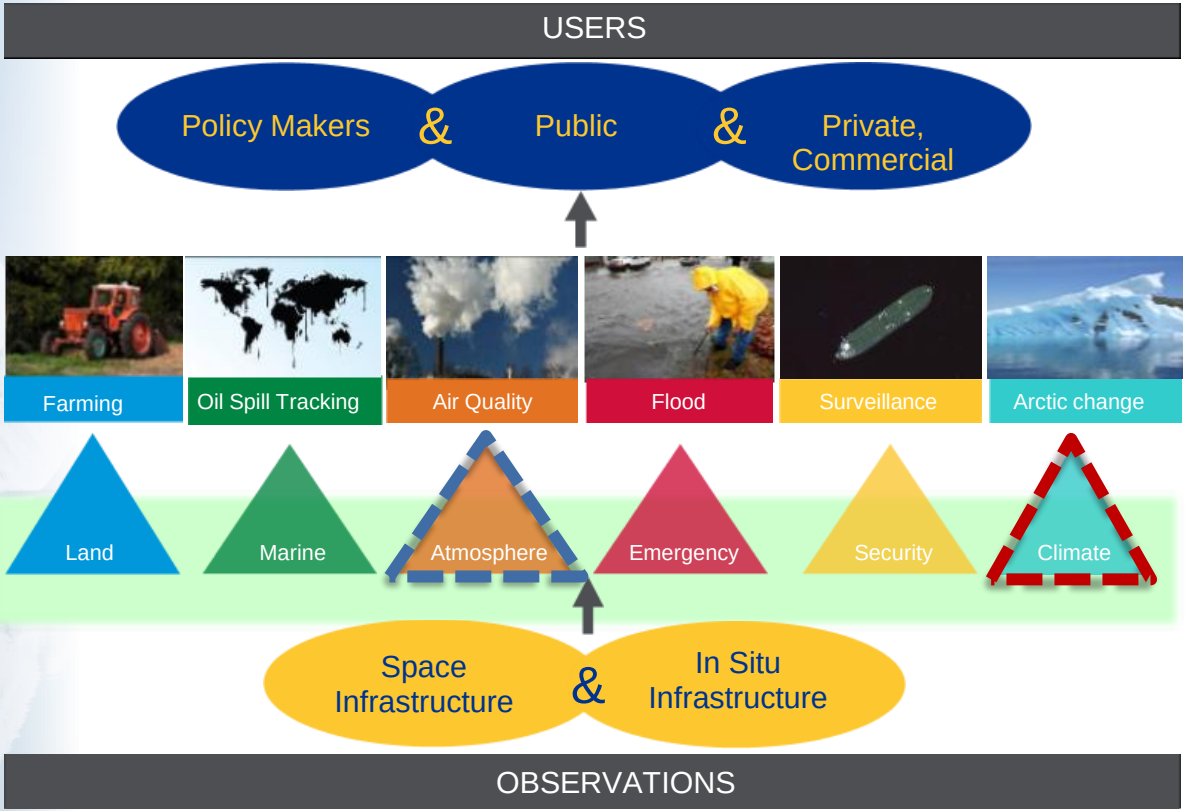
The Copernicus Climate Change Service



Different Needs

Examples of areas covered

6 Information Services

Sustainable observation capabilities

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

The C3S Climate Data Store (CDS): Providing smart data for smart decisions

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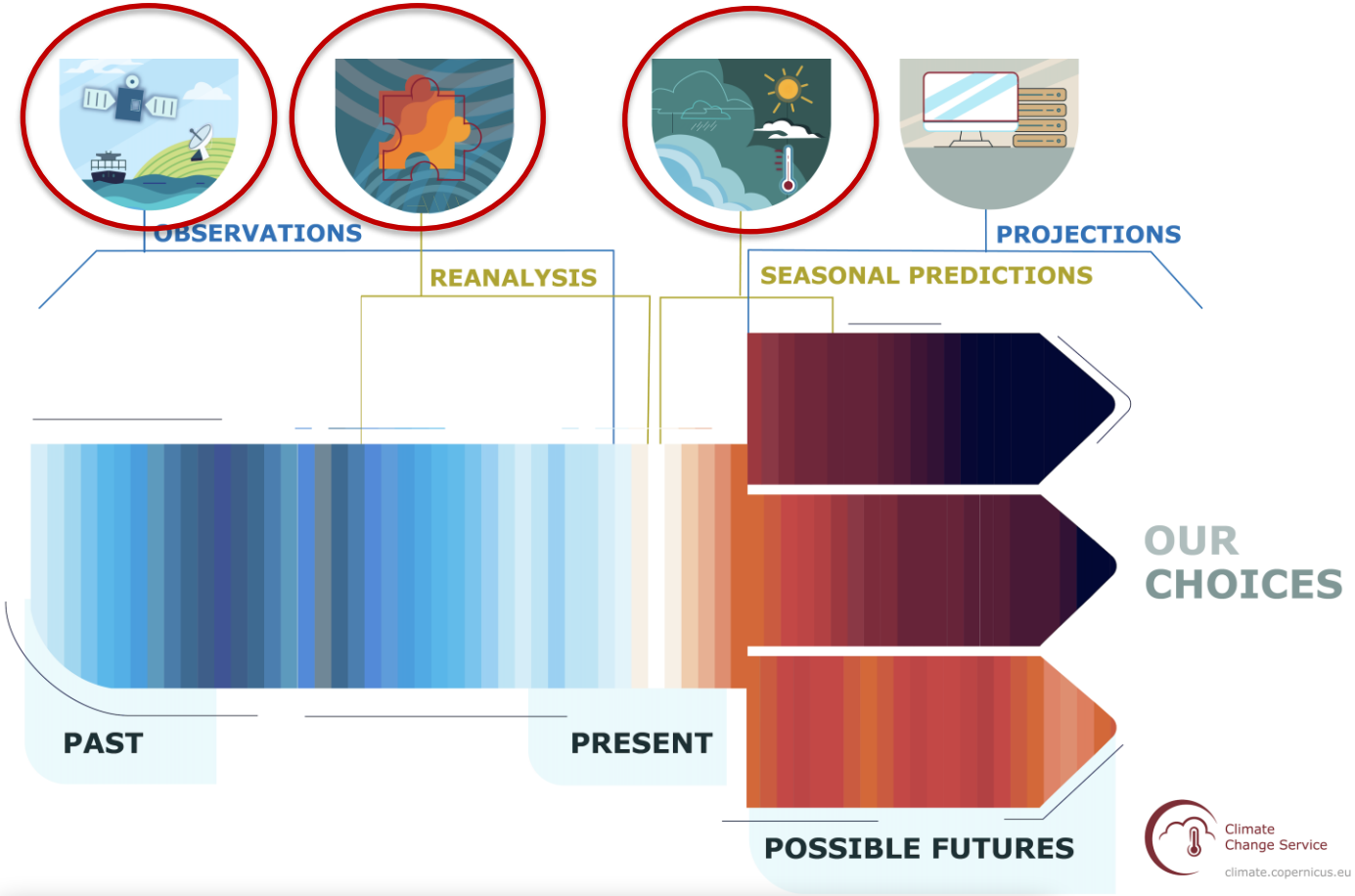
Setting the scene
Observations
Data production
Beyond data
Being operational
The next phase
User driven



Climate Change Service
climate.copernicus.eu
European Commission

Inspired by @Ed_Hawkins | @IPCC_CH

ECVs

Essential climate variables from satellite observations

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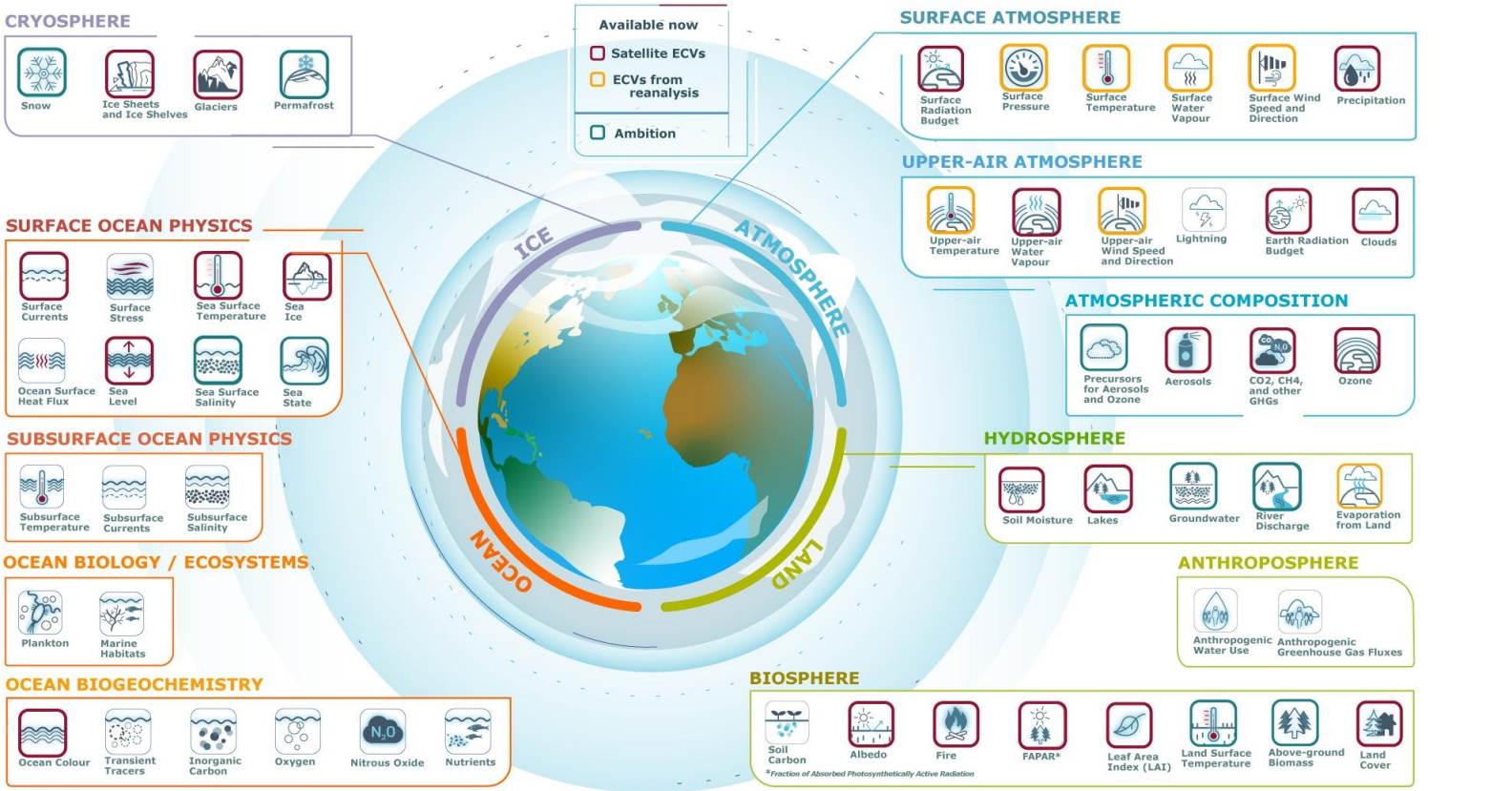
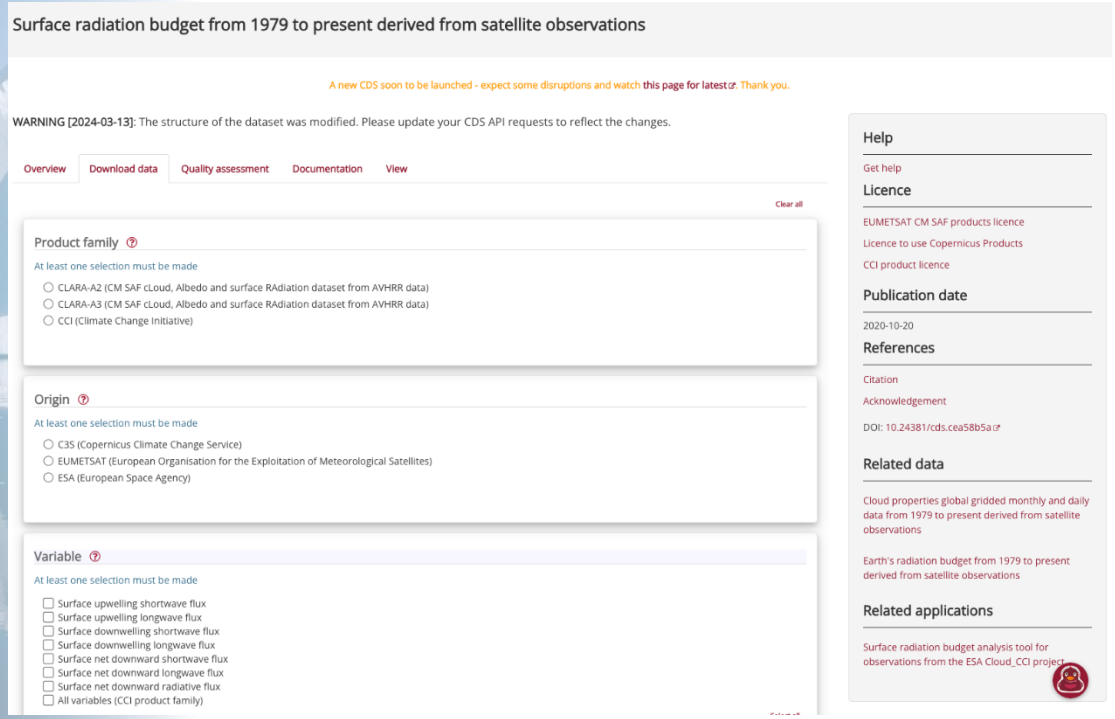
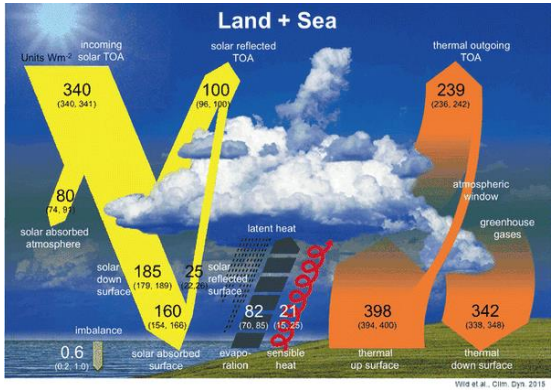
GCOS Essential climate variables (ECV)



C3S also serves ECV satellite products for Earth radiation





Many C3S ECV datasets are brokered, e.g., from ESA CCI

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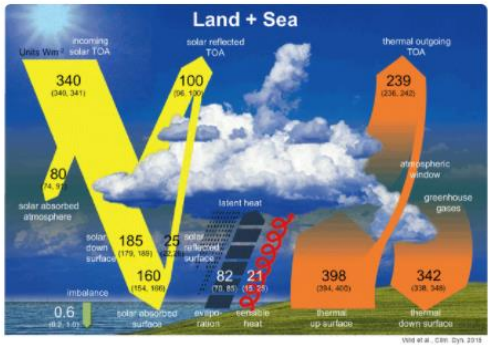
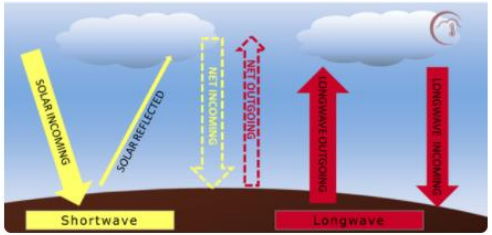
TRUTHS and ECVs

TRUTHS is a **climate mission**

Providing **benchmark measurements of solar radiation and TOA SW outgoing radiation**





→ The main value will be in the introduction of these data in the production chain of C3S Climate Data Records (CDRs) of Essential Climate Variables (ECVs) relying on the UV-NIR part of the electromagnetic spectrum.

→ TRUTHS may play a significant contribution to Surface Radiation Budget, Earth Radiation Budget, Cloud properties, Ocean Colour and Surface Albedo CDRs

→ How?

- → Enhancing calibration of existing instruments providing more accurate products backward in time
- → Providing key reference data for validation purposes
- → Extending time series of CDRs when no other data will be available or serving as an alternative source of data in the data production chains.

ECMWF Copernicus Europe's eyes on Earth European Commission

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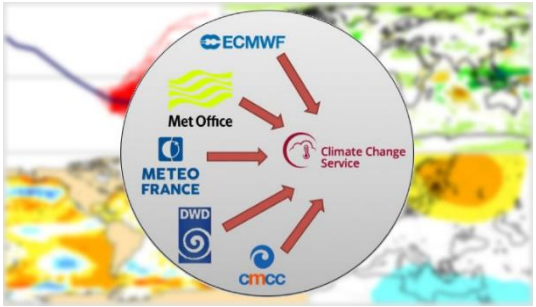
Seasonal forecasts



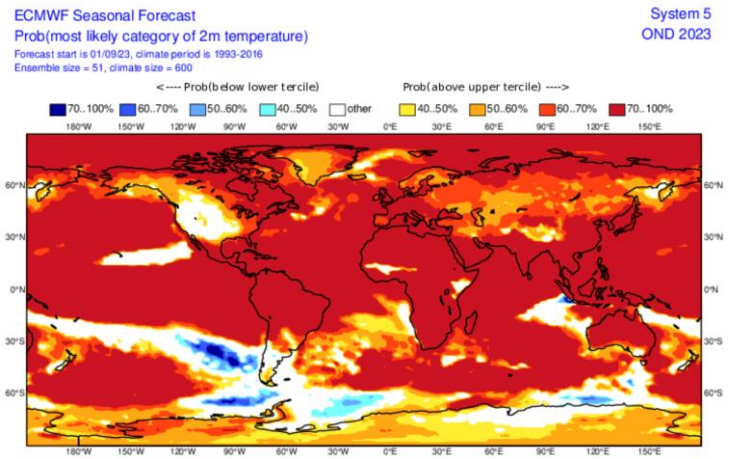
Seasonal forecasts

The C3S regularly publishes seasonal forecast products. These products are based on data from several state-of-the-art seasonal prediction systems.

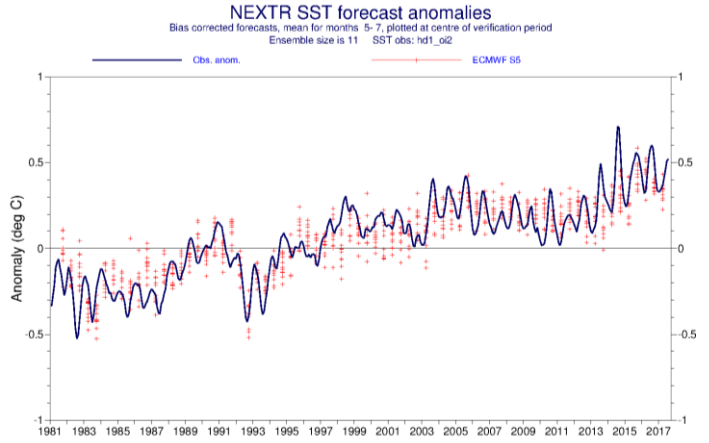
Copernicus Europe's eyes on Earth | European Commission | ECMWF

Operational seasonal forecasts

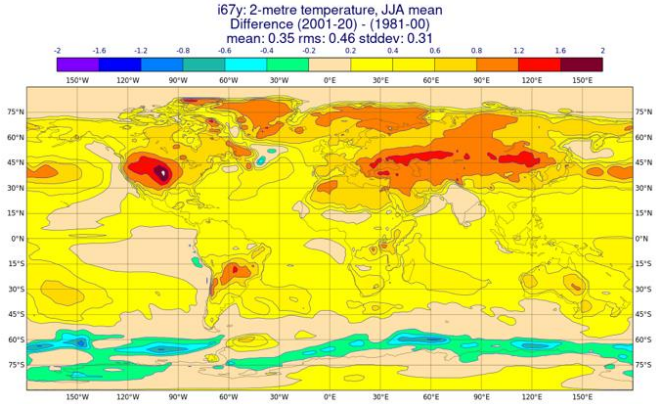
- How hot will it be in Europe this summer?
- Answer depends on knowing both year to year variability and the climate change signal.
- Is one of the **key uncertainties** in operational forecasts

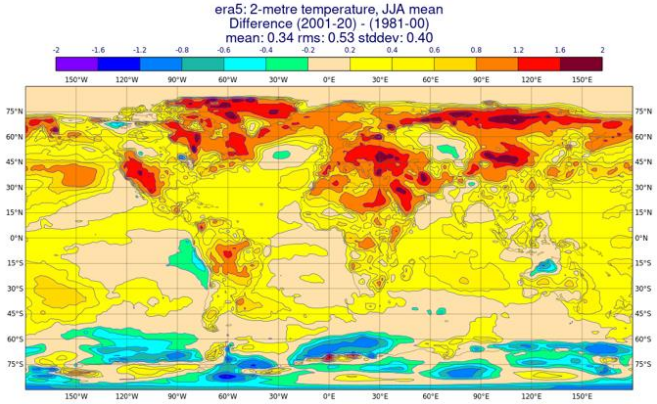


- At the technical level, real-time forecasts are calibrated against a set of re-forecasts covering the last few decades. (Presently we use 1993-2016 as a calibration period, will switch next year to using 1993-2022).
- If the real-time forecasts have an incorrect climate change signal, this will bias the real-time forecast either to be too warm or too low (globally, regionally, and with dynamic feedbacks).
- Estimates of skill from calibration period will be less affected by trend errors, so skill estimates will be biased to be overconfident.

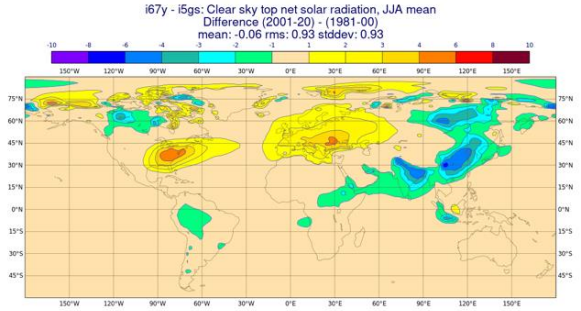


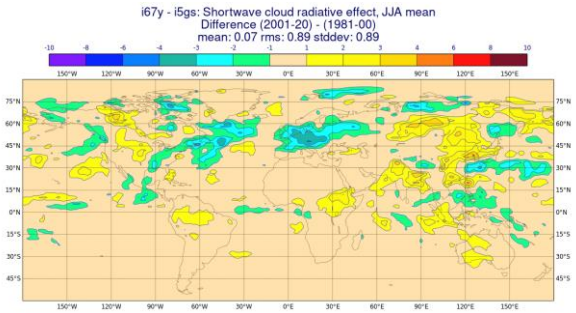
Temperature trends for JJA (2001-2020) – (1981-2000)





Forecast trends over Europe (left) are less than observed trends (right)

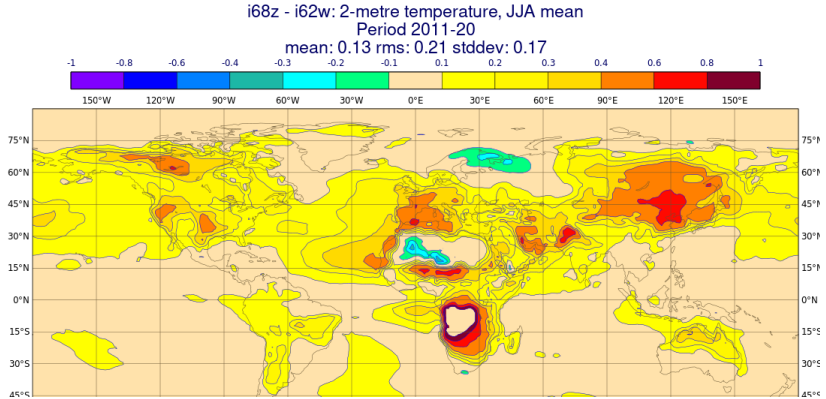


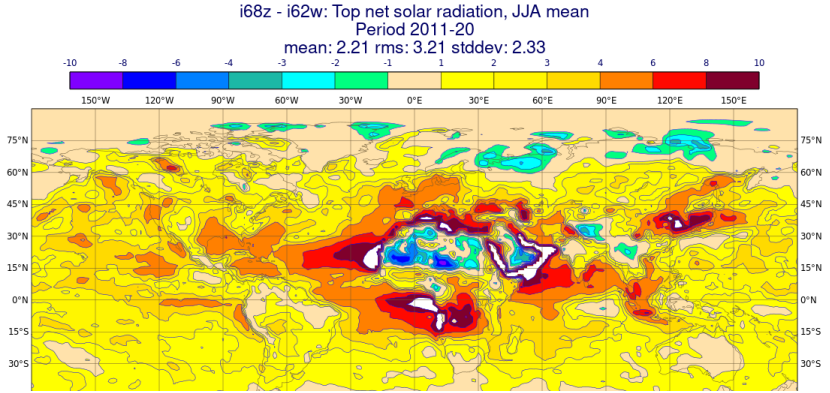


Changes in clear-sky radiation from aerosol changes are plausible (left) but are opposed over Europe by cloud feedbacks with the wrong sign (right).

Importance of validation data for the radiative budget

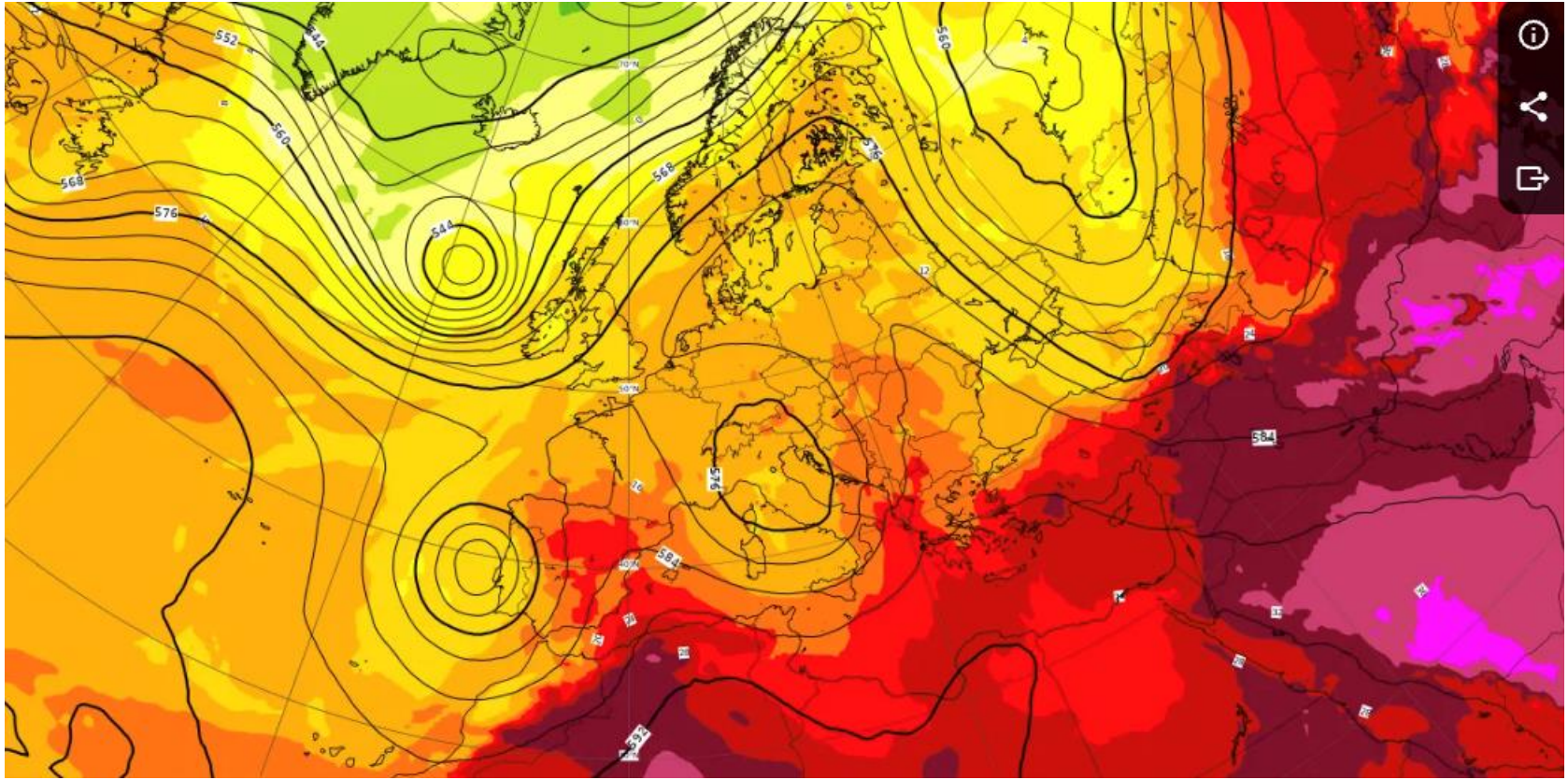
- **Small** radiative changes have **large** impact on 2m temperature in seasonal forecasts (relative to the signals we are trying to predict).
- Recent science developments such as time-varying aerosol include attempts to better capture longer-term processes and trends, but cloud changes and feedbacks are a hard problem, and accurate radiative data is crucial to improve our understanding and modelling.





Sensitivity of JJA predicted T2m from 1st May to TOA net solar radiation, assessed from seasonal forecast experiment removing tropospheric aerosol. At this timescale, T2m closely follows TOA solar, with a sensitivity of about 0.1 K per W/m2.

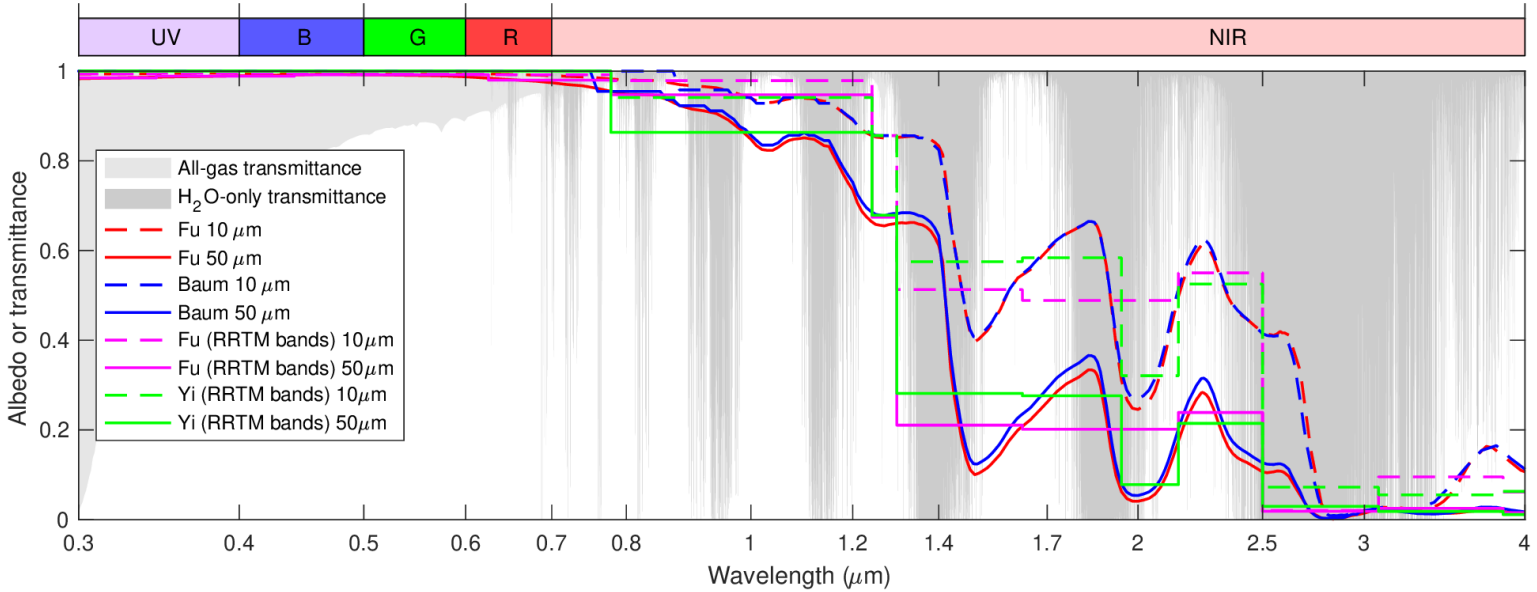
Numerical Weather Prediction at ECMWF



Physics: solar heating by ice clouds: example of spectral evaluation of models

- Ice clouds absorb significant amounts of sunlight, heating the upper troposphere which affects winds
- Absorption almost all occurs in the near-infrared
- Significant uncertainties due to *particle size*, *ice optical model* (including roughness) and *spectral averaging of optical properties to bands*

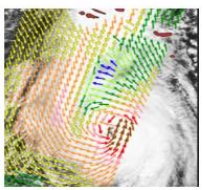
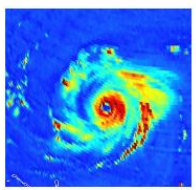
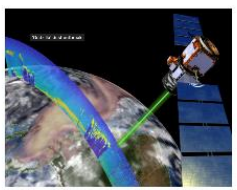
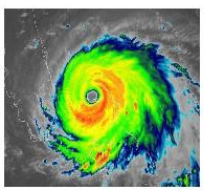
- **Comparing TRUTHS with model-computed NIR reflectance at fine spectral resolution will help diagnose errors in these aspects, improving spectral radiative heating rates in the model**
- This approach has been demonstrated from aircraft by Wolf et al. (JAS 2020)

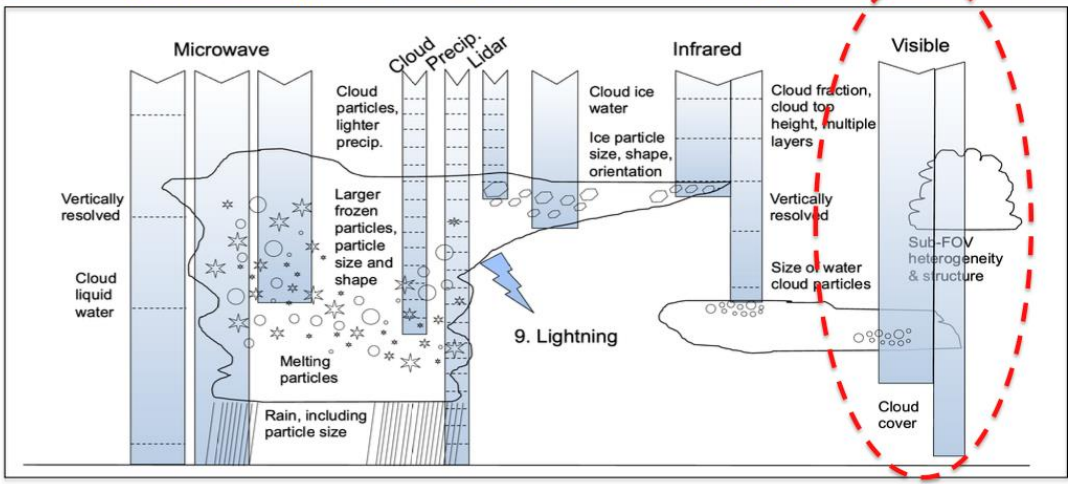


Reflectance of clouds in the optically thick limit

Current operational optical model is Fu in RRTM bands

Data assimilation: Continue to push boundaries of satellite observation exploitation

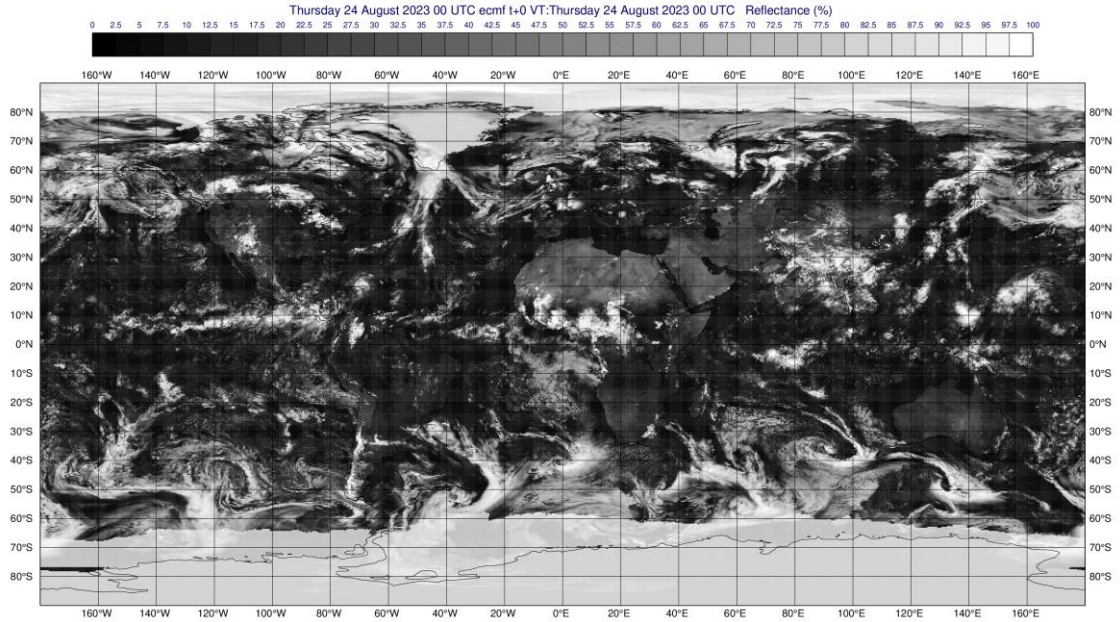





- Satellite observations make a major contribution to the Earth system data which are routinely assimilated into models to determine the initial conditions for weather forecasts.
- Short-wave (solar spectrum) frequencies are largely underused in NWP applications, compared with longwave (infrared) and microwave wavelengths.
- Short-wave reflectances exhibit complex sensitivities to clouds, aerosols and surface characteristics, which can be highly heterogeneous. Do not allow the sampling of the full diurnal cycle.
- Observations at VIS wavelengths can provide valuable additional information about clouds (esp. low-level clouds) and aerosols, that is not available from IR or MW data.

Assimilation of observations at visible wavelengths is the next exciting frontier for satellite exploitation.

Global weather forecasting – Simulated TOA reflectance (VIS0.6)



Credits: Cristina Lupu, Josef Schroettle, Philippe Lopez

- Reflectances that would be seen at a visible wavelength (640 nm) are computed during the model run from every grid point of the forecast model.
- The image product assumes a nadir view for every model grid point, free from real satellite geometry distortions at high latitudes and allows a unique perspective, to see the entire globe in perpetual daylight at a range of forecast lead times.
- Sunglint is excluded - the assumption is that both sun and satellite are overhead everywhere on the planet.

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Reanalysis

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ERA5: Global hourly resolution from 1940 to 5 days behind time operationally

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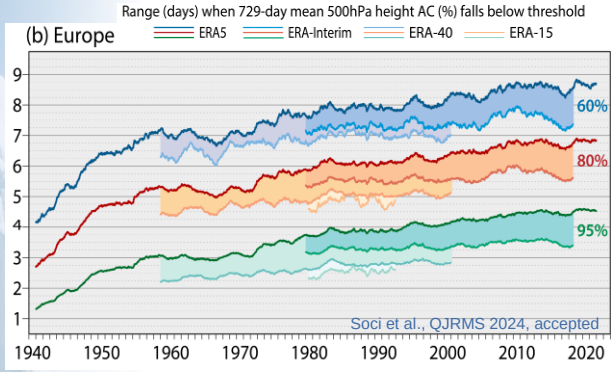
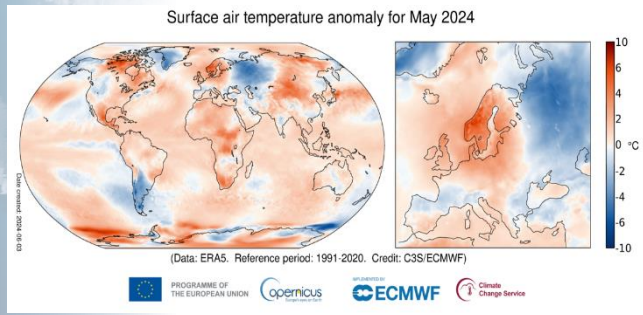
ERA5 was built on the shoulders of other ECMWF reanalyses

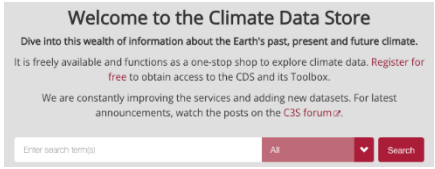


Skill of 10-day forecasts initialized from ERA against ERA at verification time

From accurate timely climate monitoring, ..



ERA5 has over **160,000 users** providing **petabytes** of climate data



OLYMPIASTADION BERLIN

Two full stadiums of the UEFA Euro 2024 final would not hold all of them

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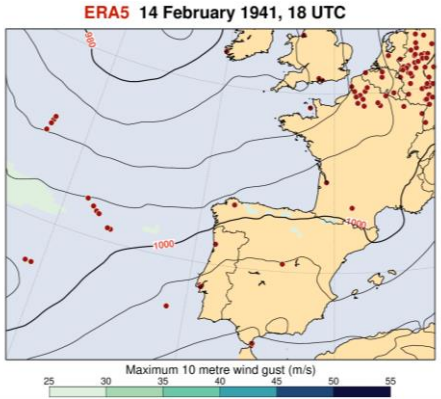
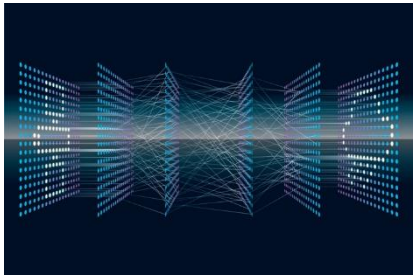
.. to historical extreme cases ..



.. and leading training set for data-driven weather forecasting and much more ...



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European Commission

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The ERA5 observing system

Over 200 types of reports

- **So far, not for Earth radiation!**
- Needs investment to become feasible, ideally via NWP

Per day: 17,000 obs in 1940, **25 Million** in 2022, 130 Billion in total, so far

Satellite observations, mostly since 1979:

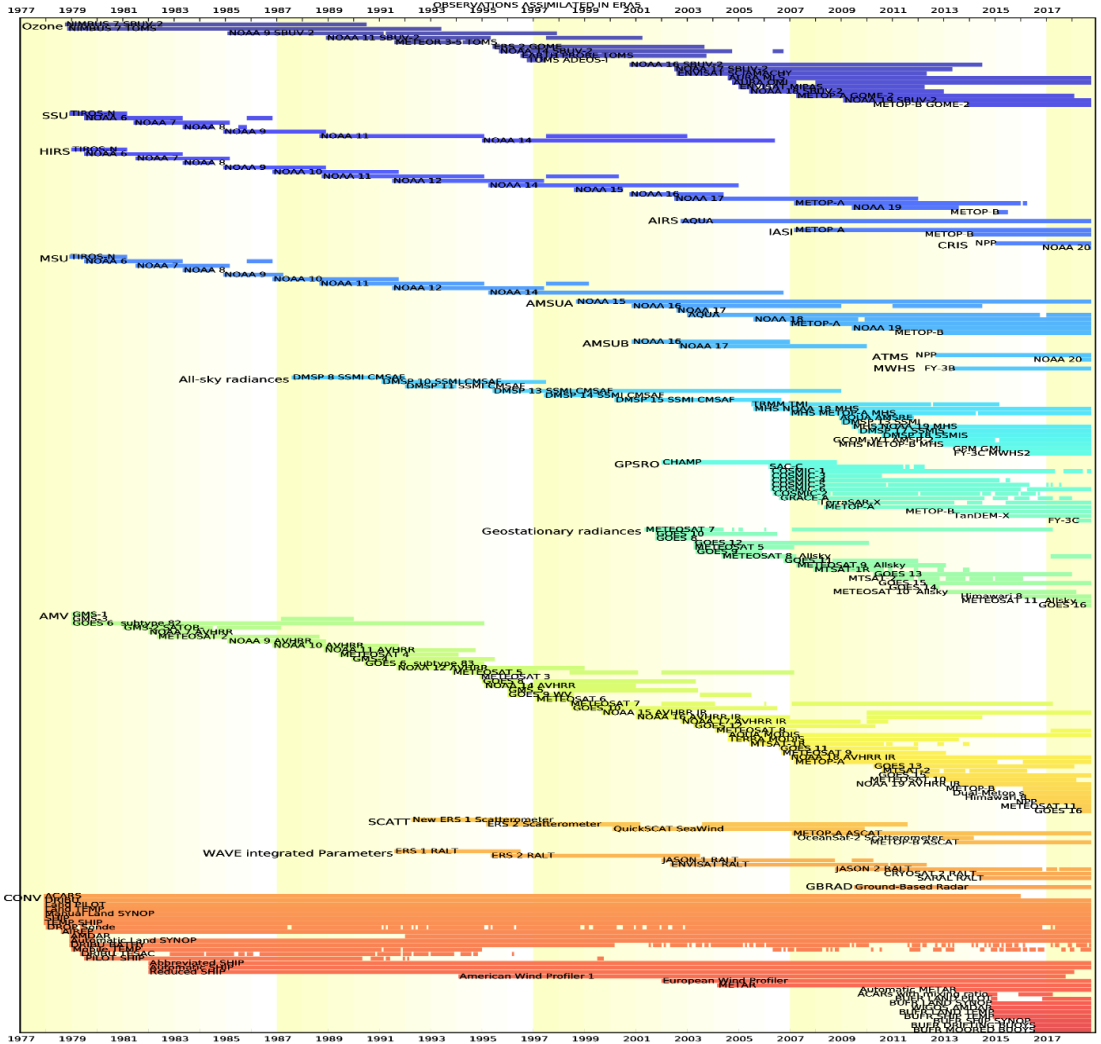
Radiances and Atm. motion vectors from LEO and GEO
GNSS-RO bending angles
Scatterometer: ocean wind + land soil moisture
Ozone level 2 retrievals + level 1B
Altimeter wave height

Conventional observations

Surface: Land stations, buoys, ships
Upper-air: Balloons, dropsondes, aircraft, profilers
Use archive created for

- ERA-40 (lack source/traceability and data license)
- NRT obs. received by ECMWF (similar remark)
- Intl. (GCOS) obs. archives: ISPD, ICOADS

+ Reprocessed satellite observations
+ Rescued in situ observations



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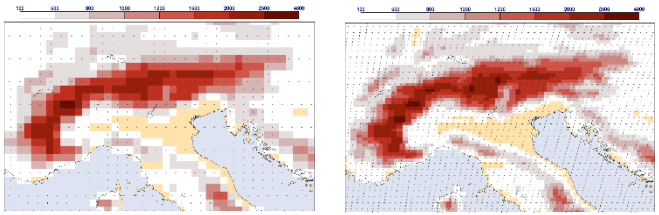
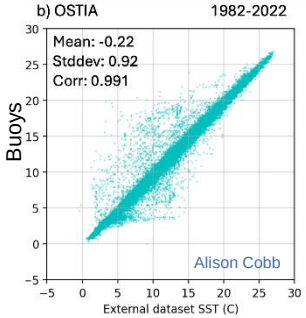
ERA6, preliminary results

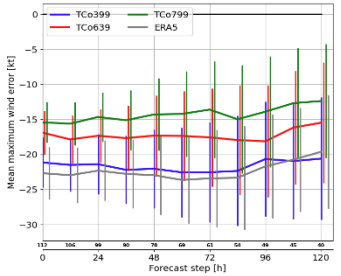
Horizontal grid: 14 vs 31km

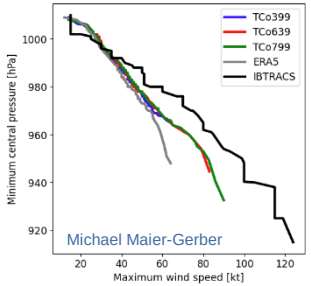


Great Lakes

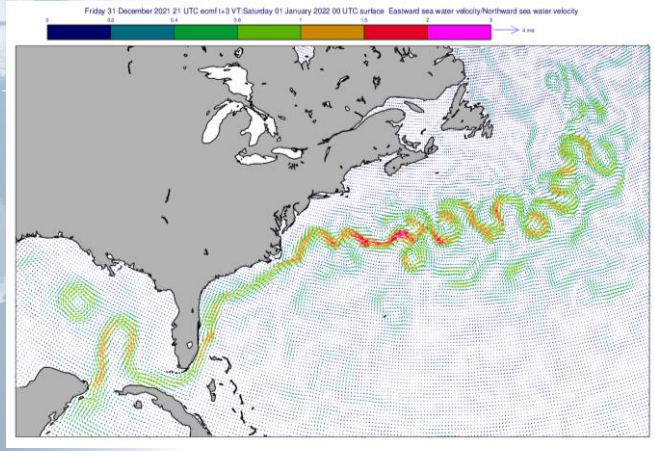


Tropical cyclones

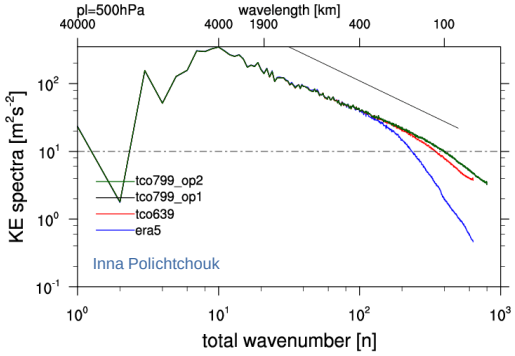




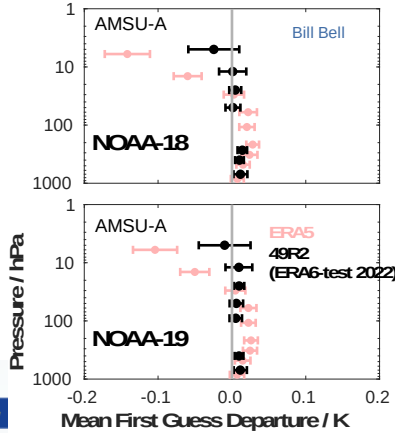
Hourly ocean currents, SST, sea ice



Energy spectra



Departure statistics



Summary: in a nutshell

Climate Change

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RMetS Royal Meteorological Society

ERA-20CM: a twentieth-century atmospheric model ensemble

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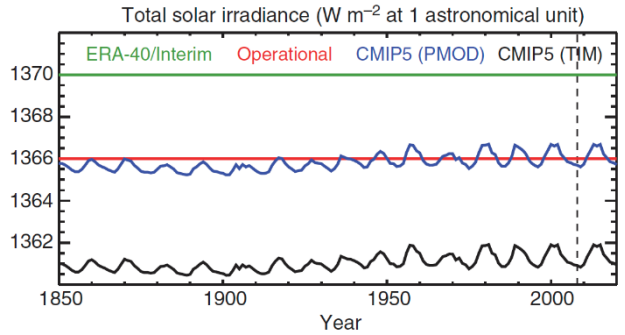
*Correspondence to: H. Hersbach, ECMWF, Shinfield Park, Reading RG2 9AX, UK. E-mail: hans.hersbach@ecmwf.int



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