

Applications of coupled data assimilation at ECMWF

Patrick Laloyaux & Antje Weisheimer

Climate reanalyses at ECMWF spanning 1900-2010

- reconstruct the past weather (synoptic situation)
- reconstruct climate (low-frequency variability)

ERA-20C: the ECMWF atmospheric reanalysis of the 20th century



Atmosphere



Land



Wave

ORA-20C: the ECMWF ocean reanalysis of the 20th century



Ocean



Sea ice

CERA-20C: the first ECMWF **coupled ensemble** reanalysis of the 20th century



Atmosphere



Land



Wave

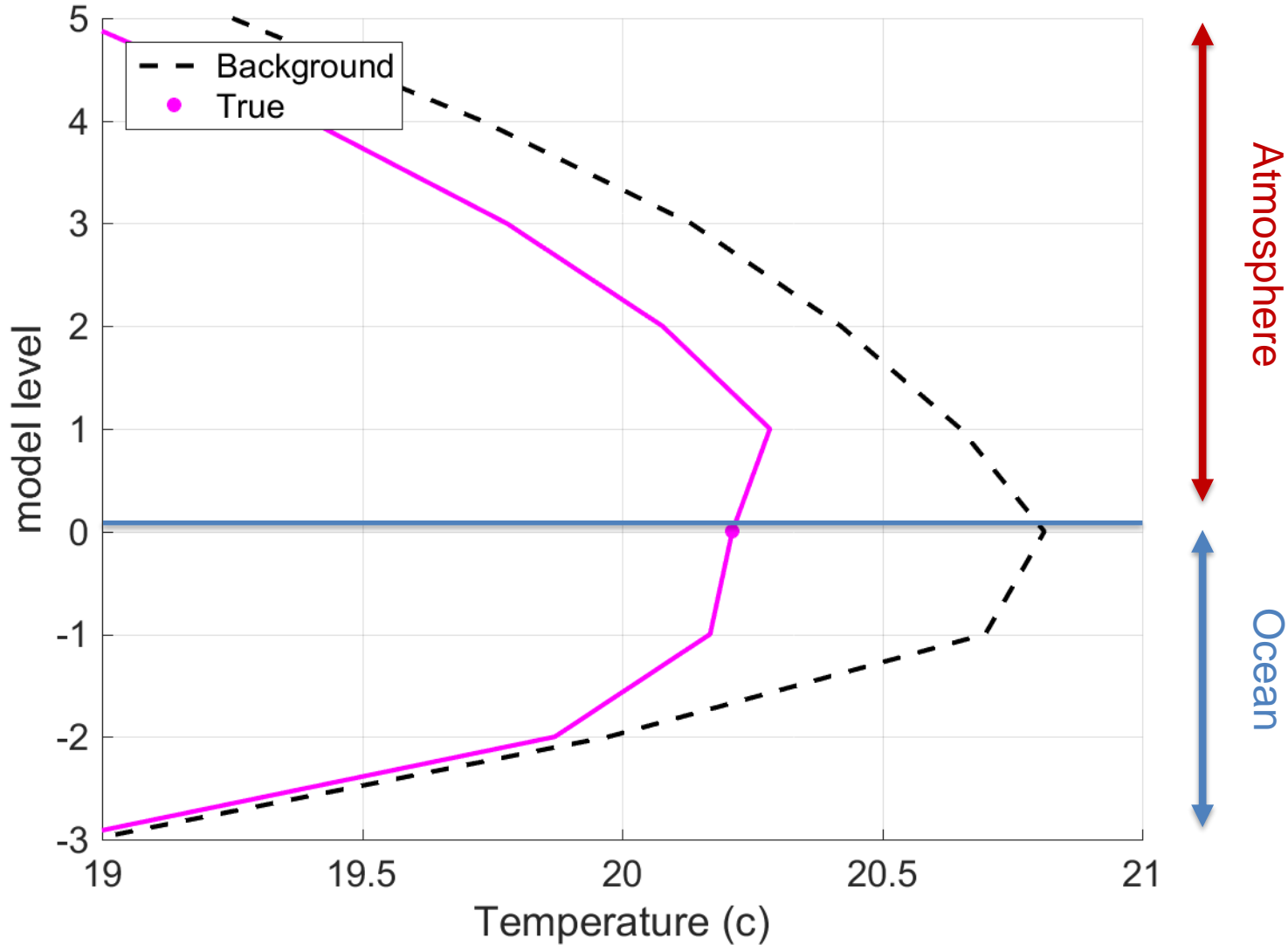


Ocean



Sea ice

Coupled data assimilation (IFS/NEMO)

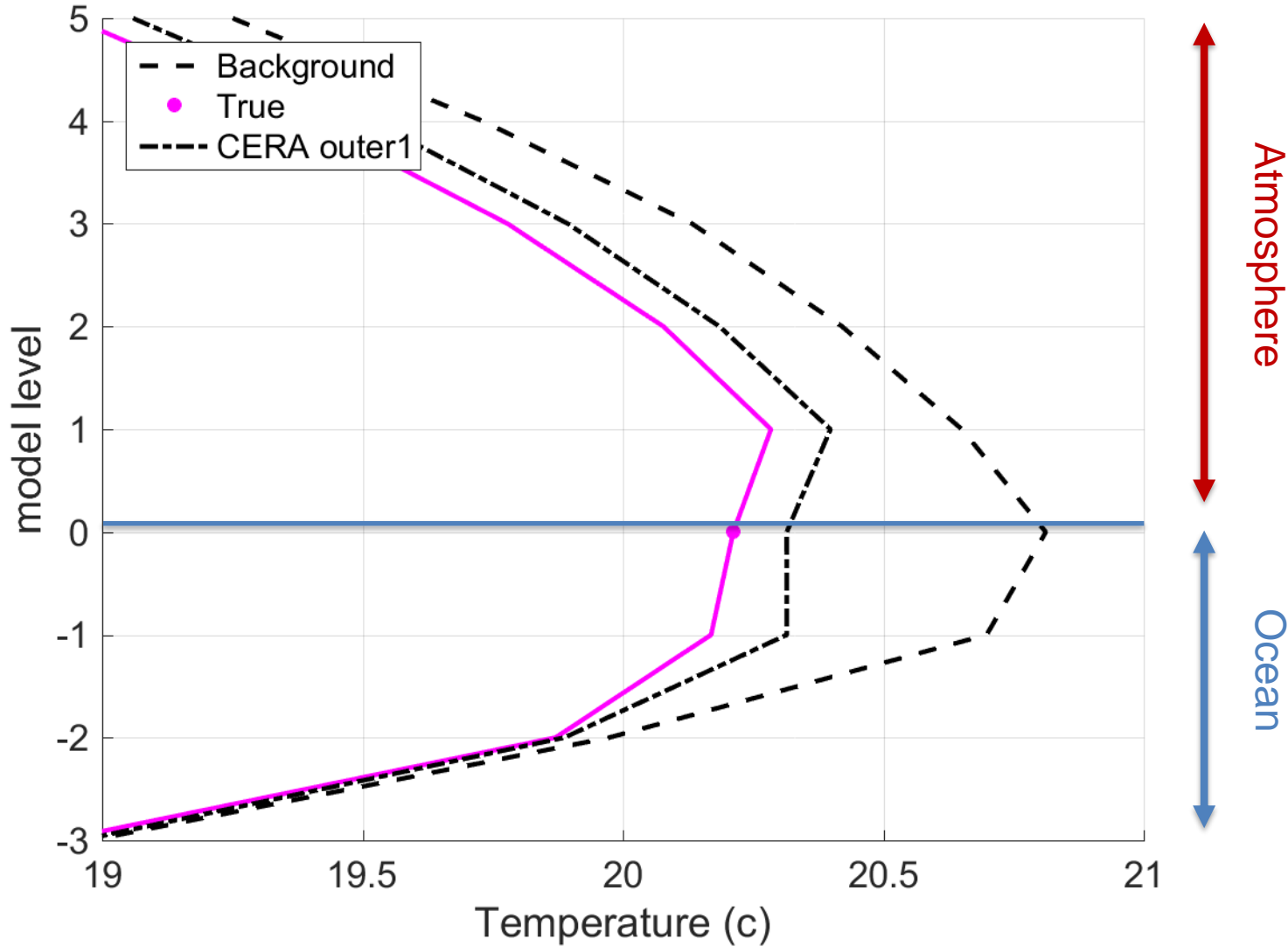


→ 4D-VAR assimilation is an iterative algorithm

→ CDA produces implicit cross-correlations using the physics of the coupled model

→ Several outer iteration to ensure a consistent coupled analysis

Coupled data assimilation (IFS/NEMO)

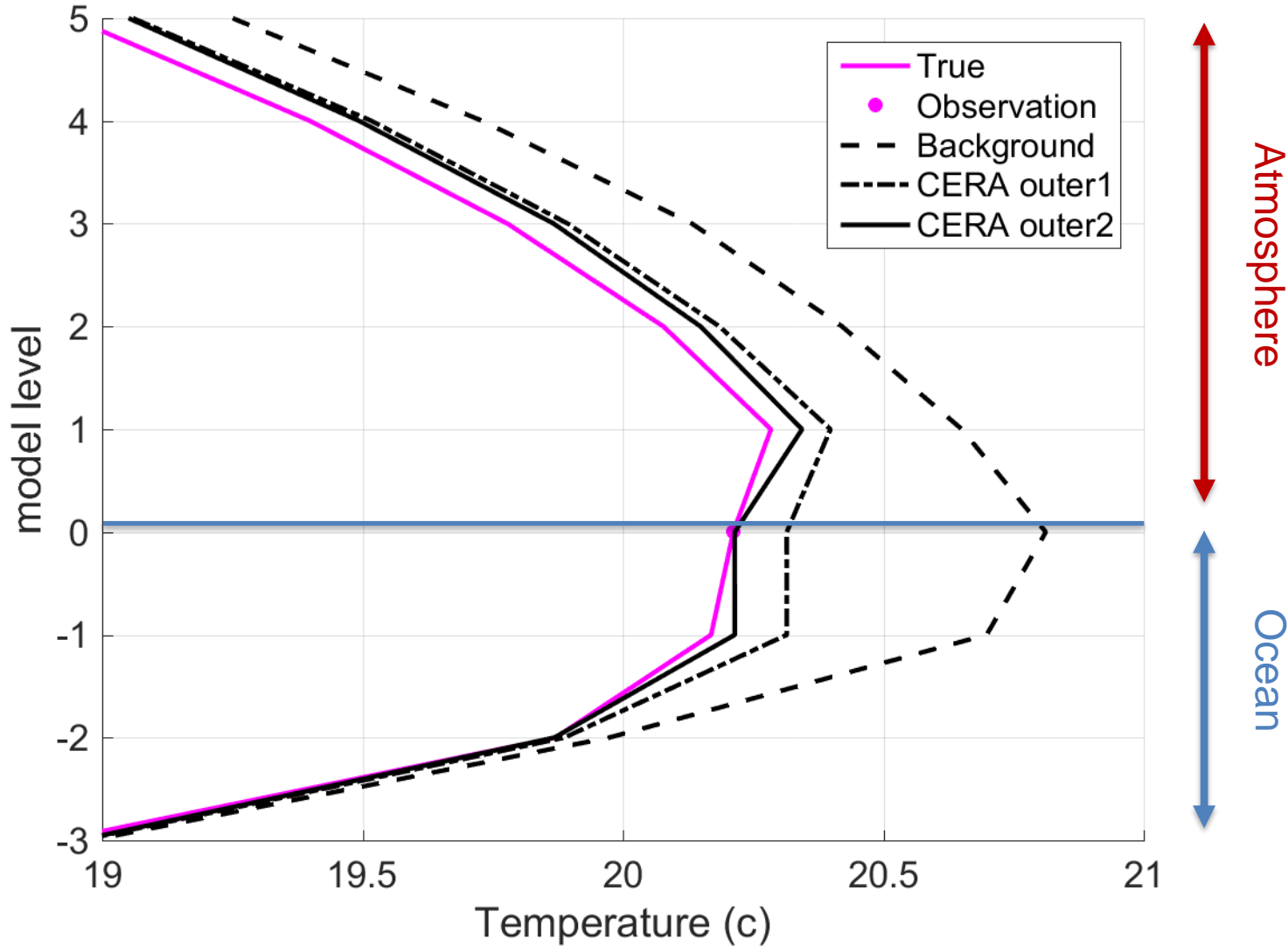


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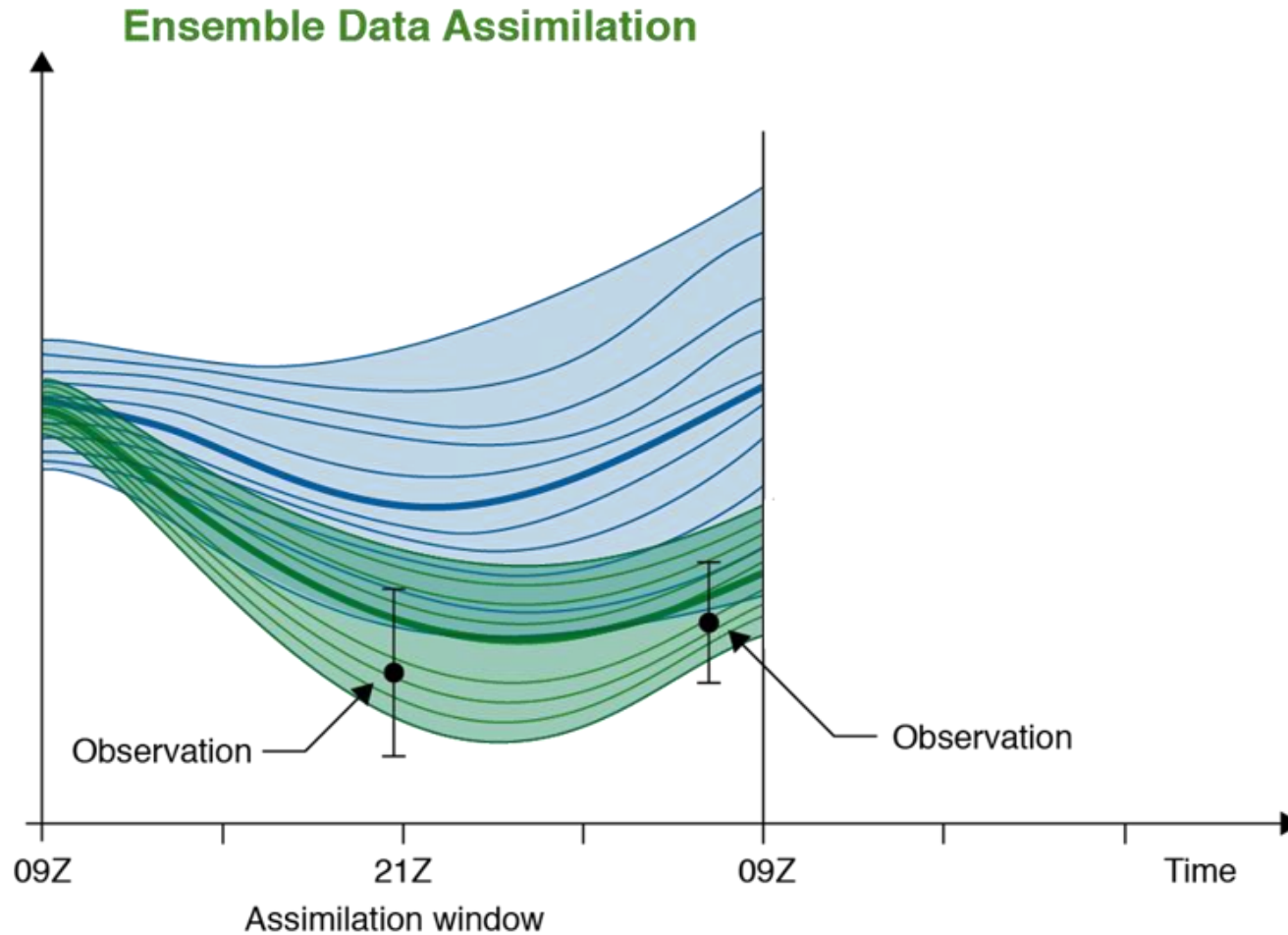


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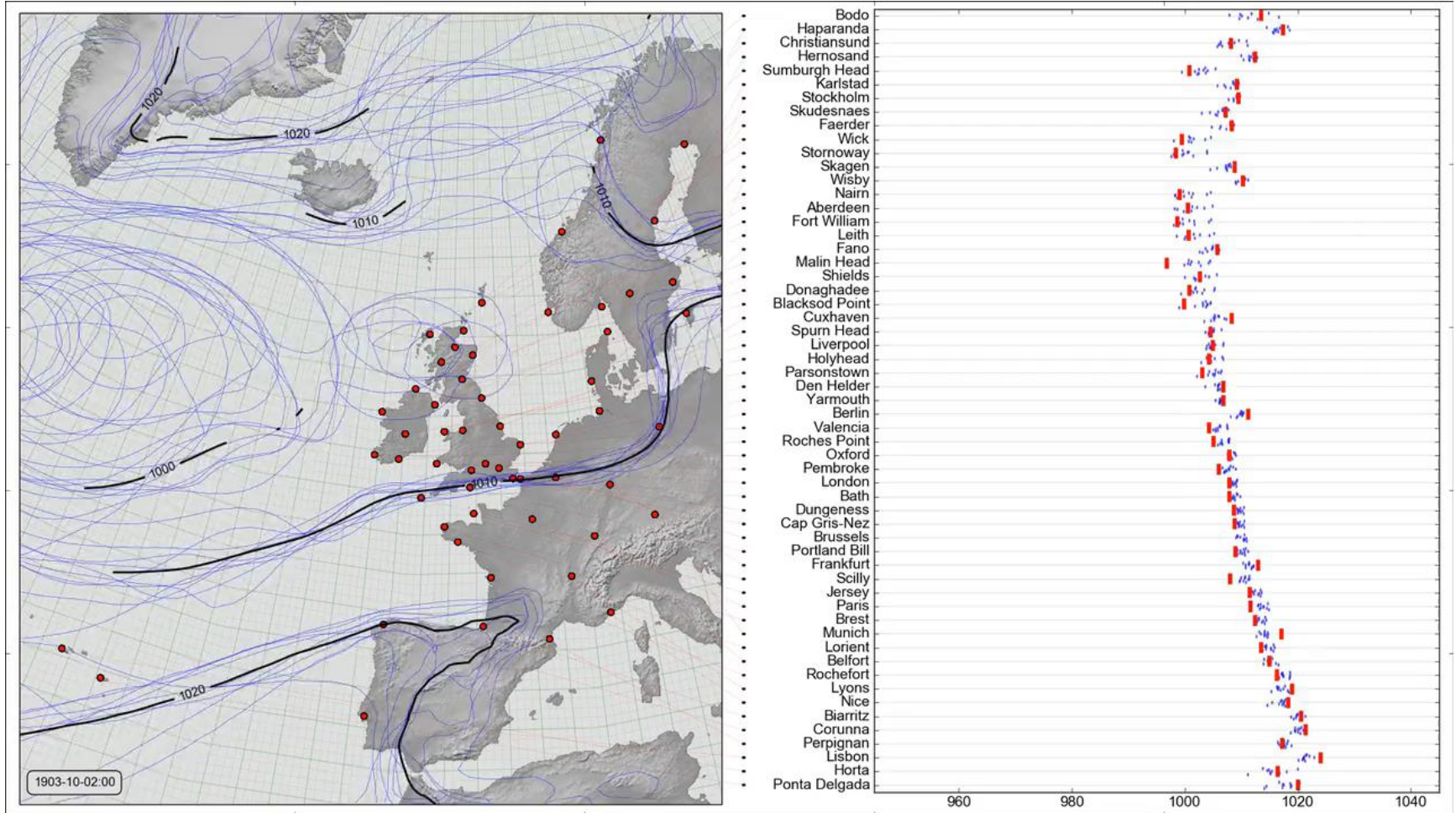
Ensemble data assimilation



*“An **ensemble of perturbed first-guesses** is transformed in an **ensemble of analysis** by running the assimilation system on each member”*

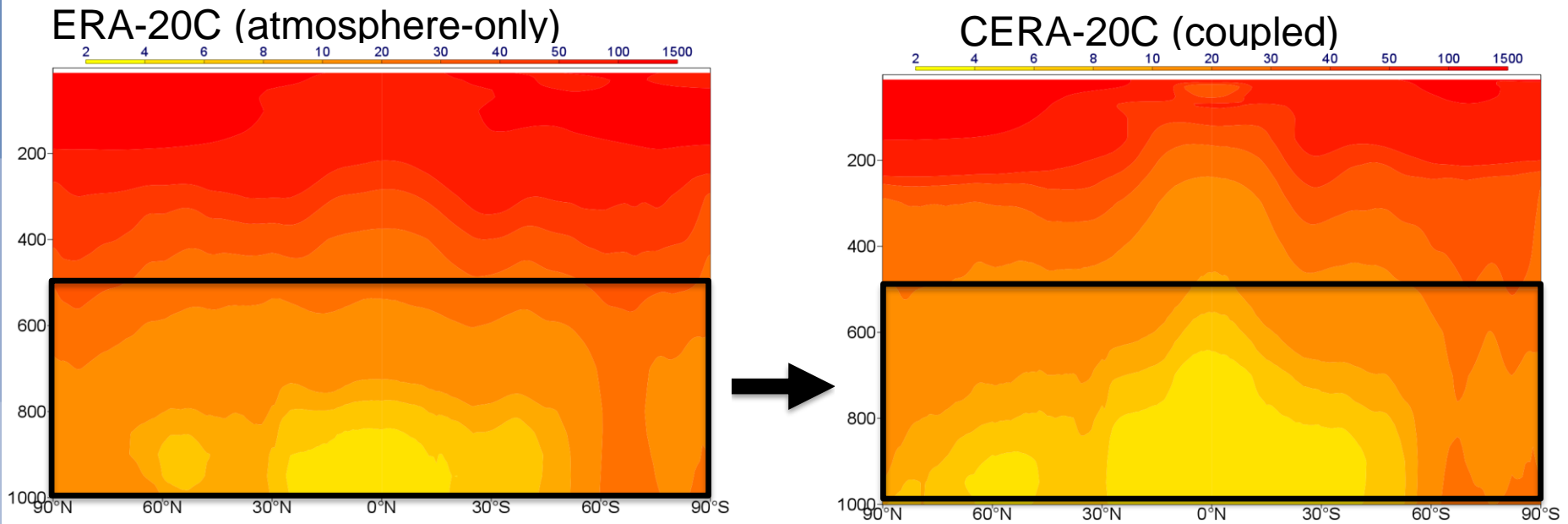
CERA-20C ensemble spread

10-member of CERA-20C showing uncertainties in the climate reconstruction



CERA-20C improved over ERA-20C

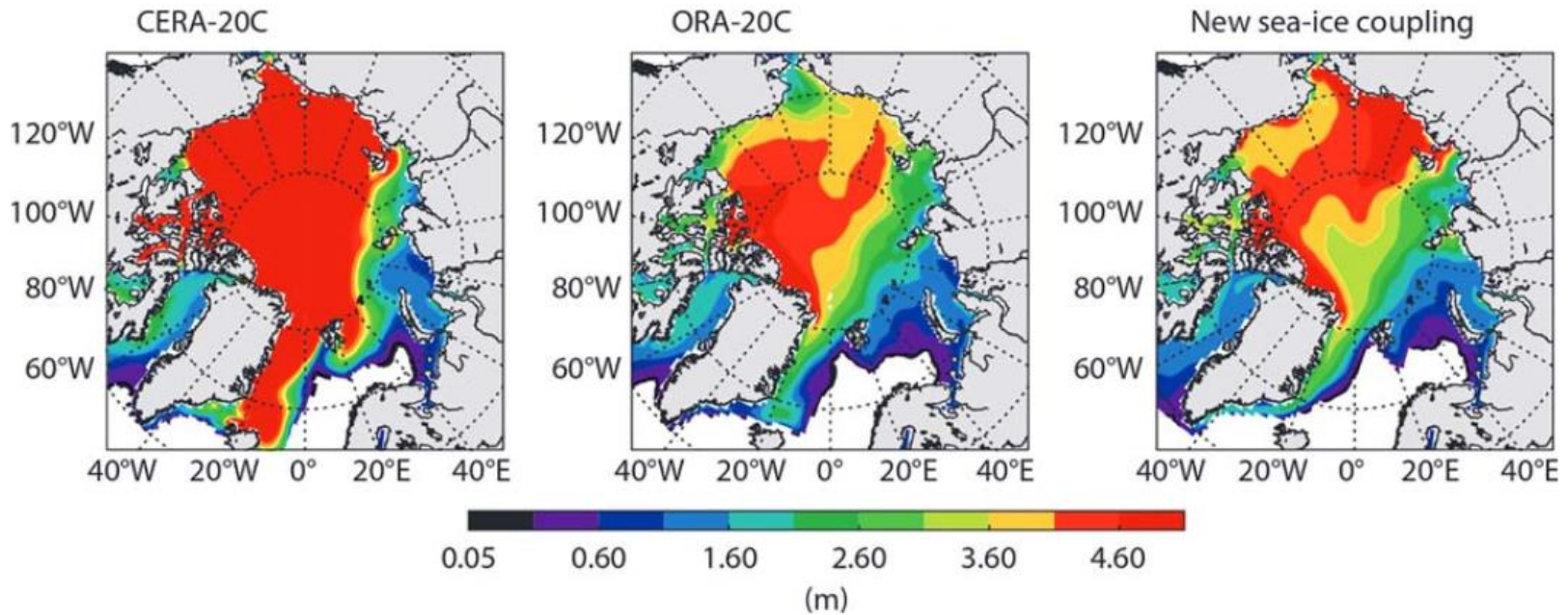
RMSE error in geopotential height for MAM 2010



CERA-20C has reduced by 20-30% the error in the troposphere compared to ERA-20C

Issue with sea ice in CERA-20C

Arctic sea-ice thickness in March 1932



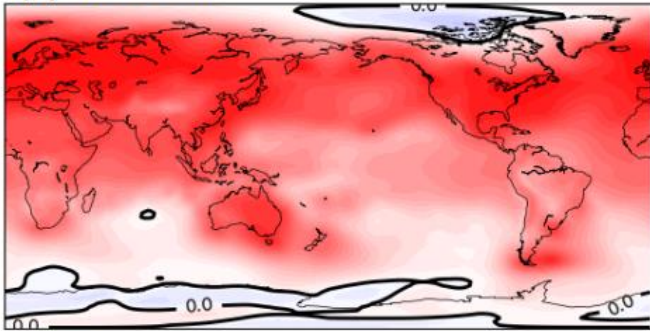
→ CERA-20C was the first application using the coupled model on an interannual time-scale

→ lack of summer melting, leading to the accumulation of Arctic sea ice over the years

→ sea-ice extent under control thanks to the SST relaxation

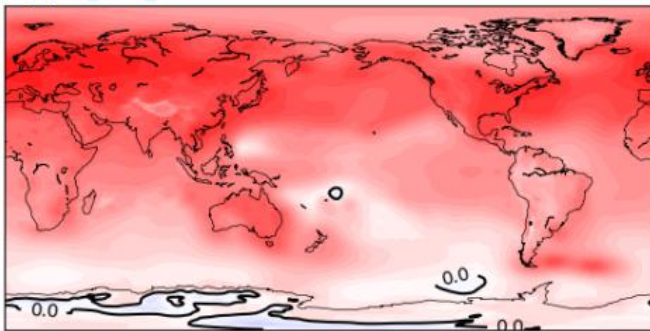
20CR reanalysis

(a) 20CRv2c



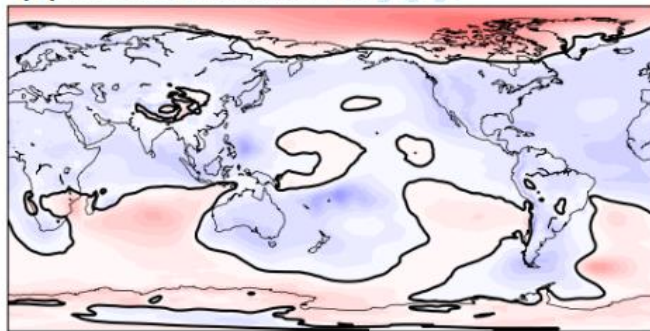
Confidence has been improved in 20CRv3 at high latitude

(b) 20CRv3



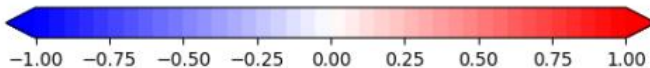
1- spread_ens/spread_clim

(c) 20CRv3 minus 20CRv2c

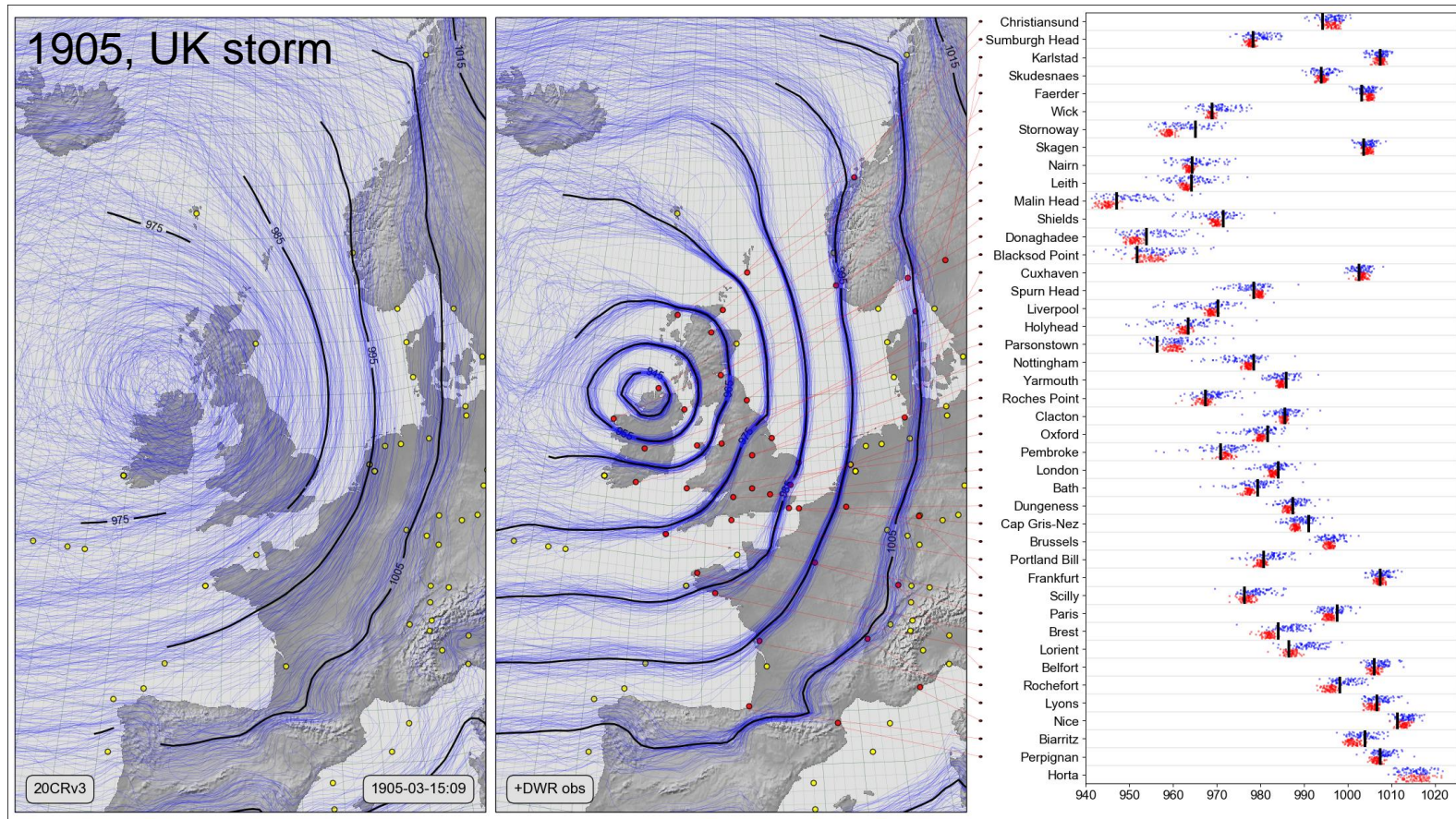


Slivinski et. al., Towards a more reliable historical reanalysis: Improvements for version3 of the Twentieth Century Reanalysis system

JFM for 1916-1918



The importance of data rescue (WeatherRescue.org)



Mean-sea-level pressure from 20CRv3 without (left) and with (right) additional observations from the UK Daily Weather Reports

Extra observations improves the representation of the storm and increase the confidence (clustering of the different members)

Skill of seasonal hindcasts initialised by climate reanalyses

Re-forecast experiments over the period 1901-2010:

ECMWF's atmospheric model with prescribed SSTs and sea-ice (uncoupled)

Initial condition: ERA-20C

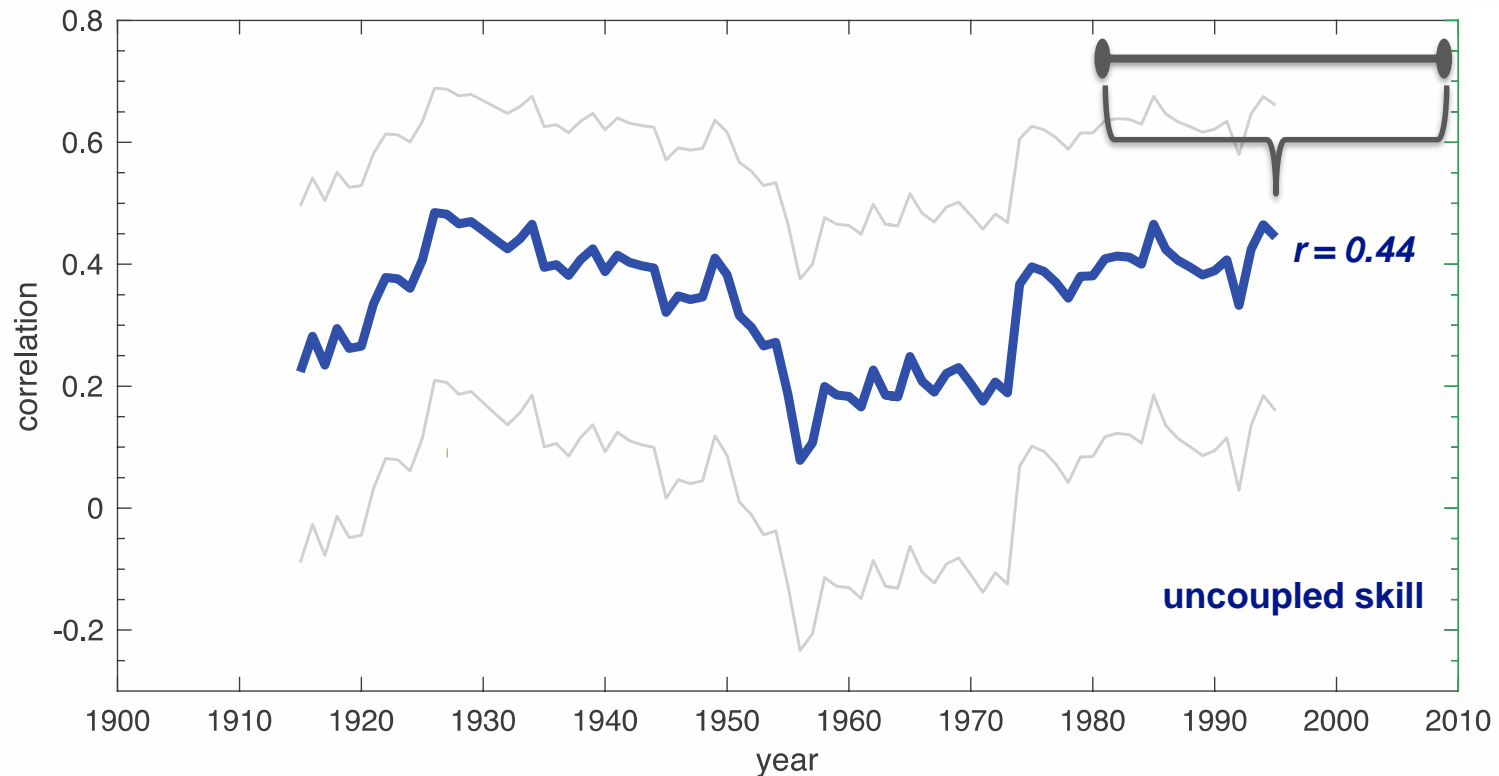
ECMWF's fully coupled atmosphere-ocean-sea-ice model (coupled)

Initial condition: CERA-20C

- IFS model cycle 41R1 (in-between S4 and SEAS5), T_L255L91 (60km))
+ NEMO ORCA1L42 + LIM2
- Ensemble with 51 perturbed members
- Focus here: 4-month forecast initialised on 1st of Nov each year (→ DJF)

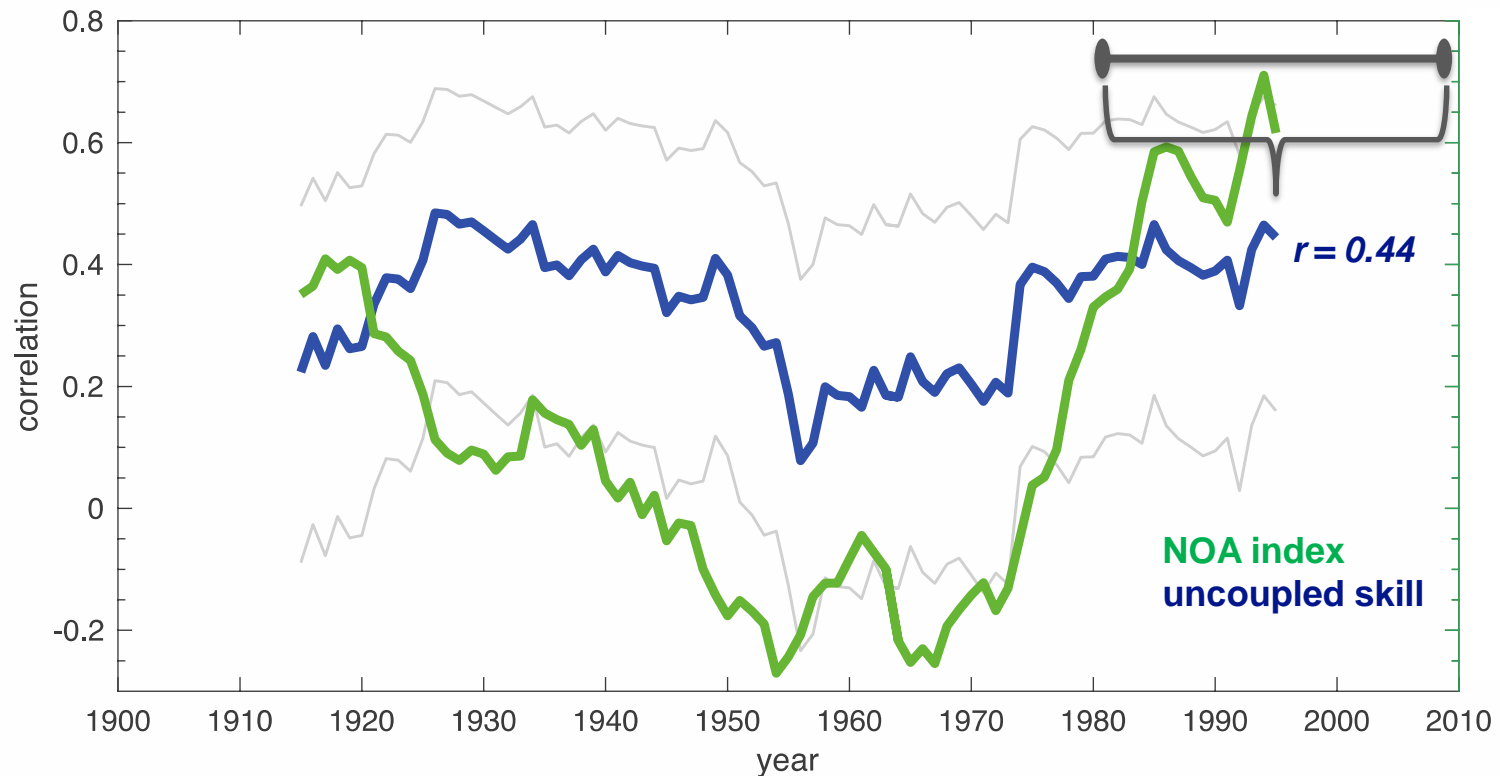
Multi-decadal variability of NAO forecast skill (moving window)

$$r_{1901-2009} = 0.31$$



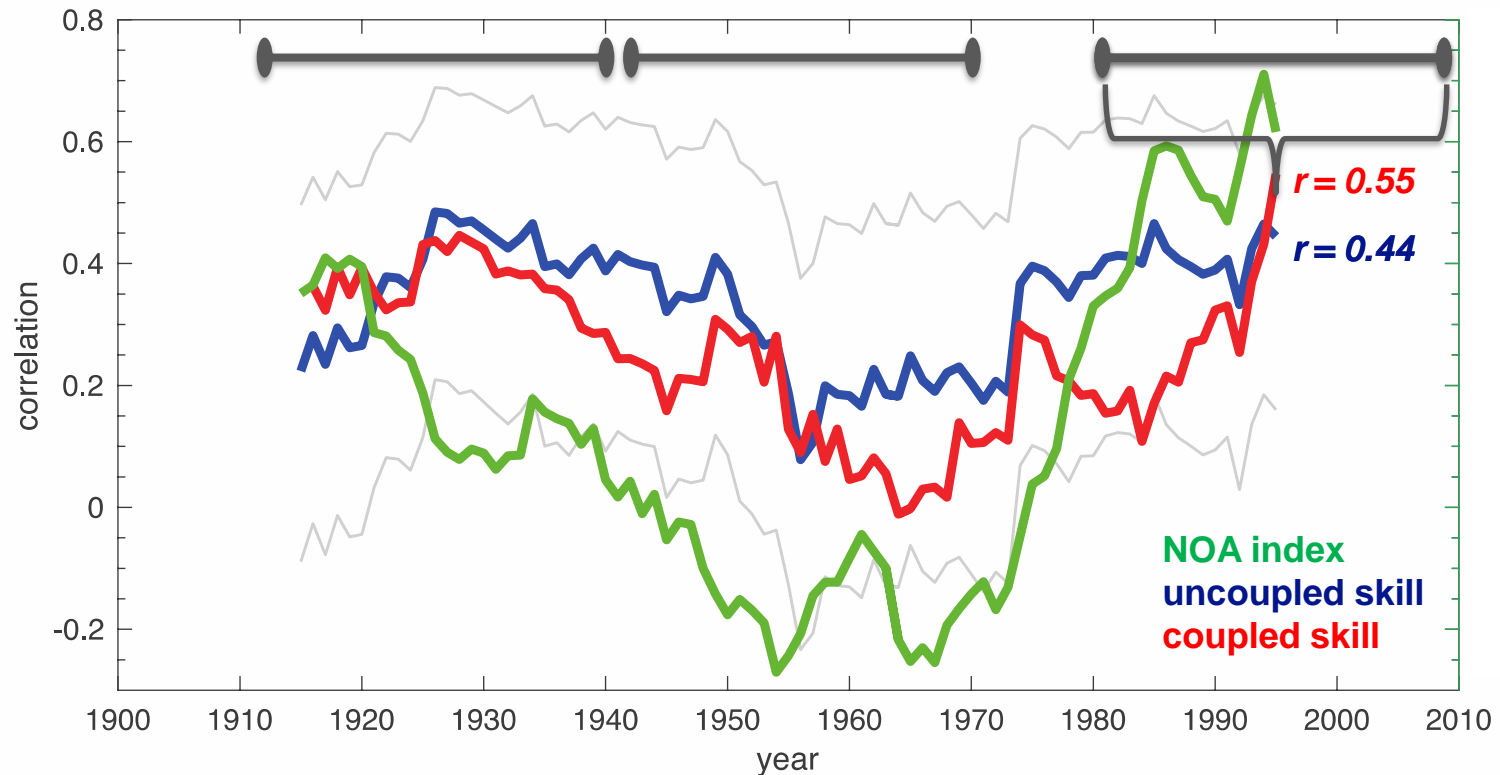
Multi-decadal variability of NAO forecast skill (moving window)

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Multi-decadal variability of NAO forecast skill (moving window)

$$r_{1901-2009} = 0.31 \quad r_{1901-2009} = 0.28$$



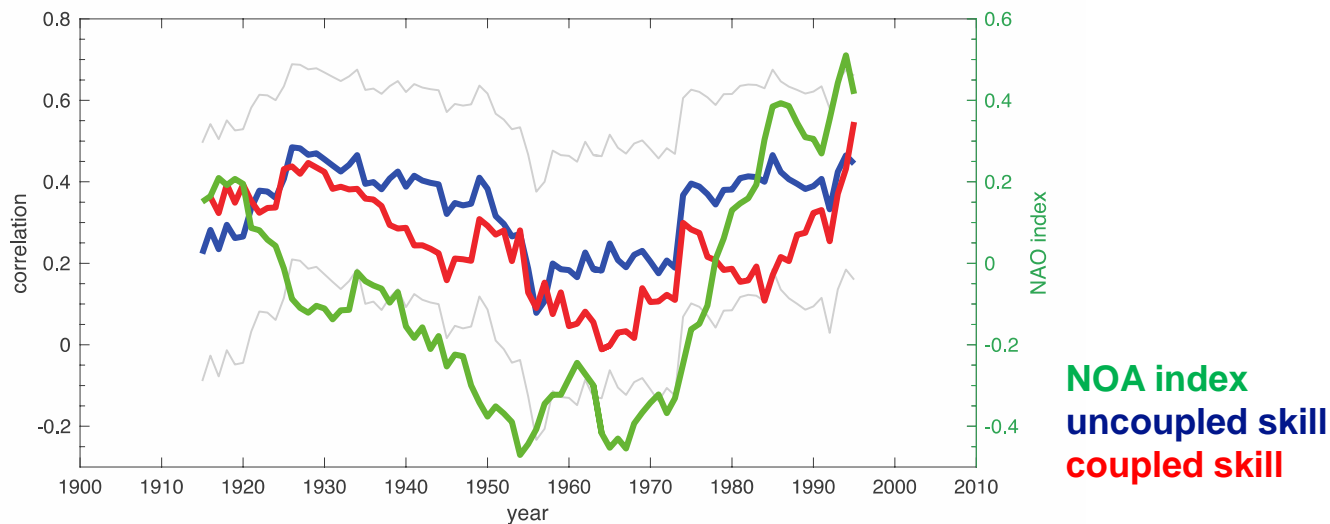
Conclusions

Reanalysis provides a consistent and comprehensive reconstruction of the climate



Multi-decadal variability of winter NAO forecast skill in coupled and uncoupled hindcasts over the 20th Century (1901-2010)

Achieving good forecast skill for recent decades is not sufficient to guarantee similar good performance in the future



CERA-20C, Synoptic Monthly Means

Type of level

- Model levels
- Potential temperature
- Potential vorticity
- Pressure levels
- **Surface**

Type

- **Analysis**
- Forecast

Select a year

- 1901 1902 1903 1904 1905 1906 1907 1908 1909 1910 1911 1912 1913
 1914 1915 1916 1917 1918 1919 1920 1921 1922 1923 1924 1925 1926
 1927 1928 1929 1930 1931 1932 1933 1934 1935 1936 1937 1938 1939
 1940 1941 1942 1943 1944 1945 1946 1947 1948 1949 1950 1951 1952
 1953 1954 1955 1956 1957 1958 1959 1960 1961 1962 1963 1964 1965
 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978
 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991
 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004
 2005 2006 2007 2008 2009 2010

<https://apps.ecmwf.int/datasets/data/cera20c>



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RESEARCH ARTICLE

CERA-20C: A Coupled Reanalysis of the Twentieth Century

10.1029/2018MS001273

Key Points:

- CERA-20C reconstructs the past climate of the atmosphere, ocean, land, waves, and sea ice
- CERA-20C provides a 10 member ensemble of reanalyses to account for errors
- CERA-20C shows significant improvements in the troposphere, compared to ERA-20C and 20CRv2c

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Abstract CERA-20C is a coupled reanalysis of the twentieth century which aims to reconstruct the past weather and climate of the Earth system including the atmosphere, ocean, land, ocean waves, and sea ice. This reanalysis is based on the CERA coupled atmosphere-ocean assimilation system developed at ECMWF.