Rate of retreat of the Arctic sea-ice boundary from reanalysis

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Research Questions

Things we are trying to find out from sea-ice

1. Can we construct a single metric for the change in sea-ice boundary from reanalysis that can be forecast ?
2. Can we relate this metric to changing greenhouse gas (GHG) emissions ?
3. Is the reanalysis good enough at high latitudes ?
4. What is our best estimate of the Arctic temperature anomaly* ?

* In the context of the GloSAT project (https://glosat.org) that is rescuing and homogenizing historical global surface air temperatures, understanding how the sea ice boundary is changing is important for knowing how to merge land and ocean temperature anomalies.

Mikhail Budyko's climate predictions in 1972

Between a snowball Earth and an ice-free planet

The Future Climate

M.I. Budyko

Man and Climate

The influence of man on climate began to show itself as early as several thousand years ago. In many areas forests gave way to cultivated land, which resulted in an increase in surface wind speed, and some change of temperature and humidity in the lower boundary layer, as well as a change in the regime of soil moisture, evaporation, and river runoff. Another effect of man's activity upon climate is artificial irrigation, which has been applied in arid regions for many centuries. Irrigation appreciably increases evaporation from the earth's surface, causing temperature decrease and an increase in relative humidity. Observations have shown that the effect of forest felling and irrigation on meteorological conditions is limited only to changes in local climate, i.e., the climate of the regions where pertinent measurements are carried out [*Landsberg*, 1970].

In recent decades man's impact on meteorological regimes has increased. This increase is associated, in particular, with a wide-scale development of field-protecting afforestation, drainage of marsh-ridden areas, and building of reservoirs.

Shelter belts lower the wind speed over fields between belts and weaken the intensity of vertical air motions near the earth's surface. This minimizes the possibility of dust storm occurrence and prevents the blowing of snow from fields in the cold season of the year. The drainage of oversaturated soil generally has an effect on climatic conditions opposite to that of irrigation. When swamps are drained, the soil moisture is reduced, its temperature rises, and evaporation decreases.

Some changes of climate are observed in the regions of large reservoirs. Building of reservoirs decreases the roughness of the earth's surface, which promotes a stronger wind. The creation of a water storage basin usually leads to a decrease in diurnal temperature variations as well as an increase in evaporation.

Although amelioration measures are conducted over vast and still extending areas, studies have shown that they, like the building of reservoirs, do not exert a noticeable influence upon the global climate.

However, there are other ways in which economic activities influence atmospheric processes that could lead to global climatic changes. It is known that billions of tons of coal and oil are burned every year, and as a result an enormous amount of carbon dioxide enters the atmosphere. If all the carbon dioxide produced by man remained in the atmosphere, its concentration would grow rapidly. However, because of the constant exchange of carbon dioxide between the atmosphere and the ocean (which can absorb a great amount of carbon dioxide), only part of anthropogenic carbon dioxide remains in the atmosphere. The data available have shown that in recent decades the amount of carbon dioxide in the atmosphere has grown by 10%–15% in the last century, and now this amount continues rising by approximately 0.2% a year.

Carbon dioxide has a certain effect on the atmospheric thermal regime. Since it does not seriously impede the shortwave solar radiation approaching the earth's surface and appreciably attenuates the long-wave heat radiation outgoing to the space, an increase in the carbon dioxide concentration raises the temperature near the earth's surface. The calculations made have shown that by the end of our century such a temperature rise may account for about 0.5° [*Study of Man's Impact on Climate*, 1971].

Among other consequences of man's activities affecting climate, the growth of energy production should be mentioned. All the energy consumed by man is eventually transformed into heat, its major portion acting as an additional source of energy for the earth that contributes to temperature rise.

Of all the more or less substantial components of the present consumption of energy by man, only water power and transformation of solar energy into wood and fiber do not change the heat balance of the earth

Budyko, Mikhail I. "The future climate." Eos, Transactions American Geophysical Union 53.10 (**1972**): 868-874.

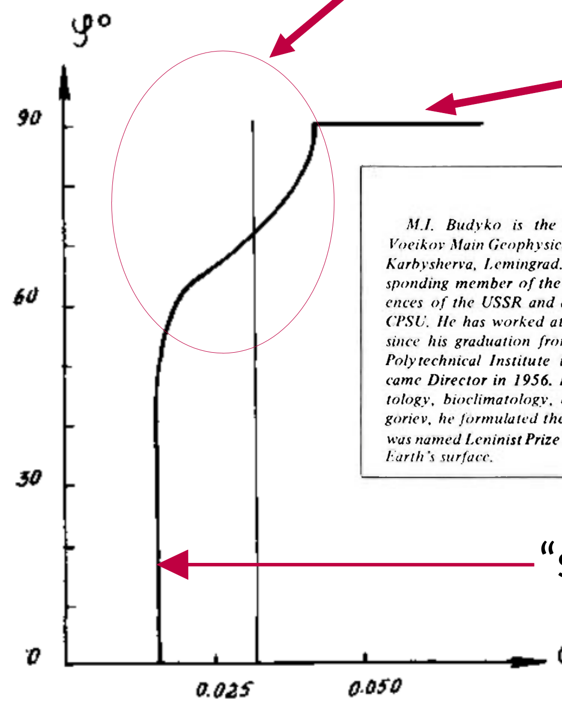

Fig. 3. Dependence of mean latitudinal ice cover boundary on carbon dioxide concentration.

M.I. Budyko is the Director of the Voeikov Main Geophysical Observatory, 7 Karbysherva, Leningrad. He is also corresponding member of the Academy of Sciences of the USSR and a member of the CPSU. He has worked at the observatory since his graduation from the Leningrad Polytechnical Institute in 1942 and became Director in 1956. His basic work is in the field of physical climatology, bioclimatology, and actinometry. With academician A.A. Grigoriev, he formulated the periodic law of geographic zoning. In 1958 he was named Leninist Prize Laureat for his work on thermal balance of the Earth's surface.

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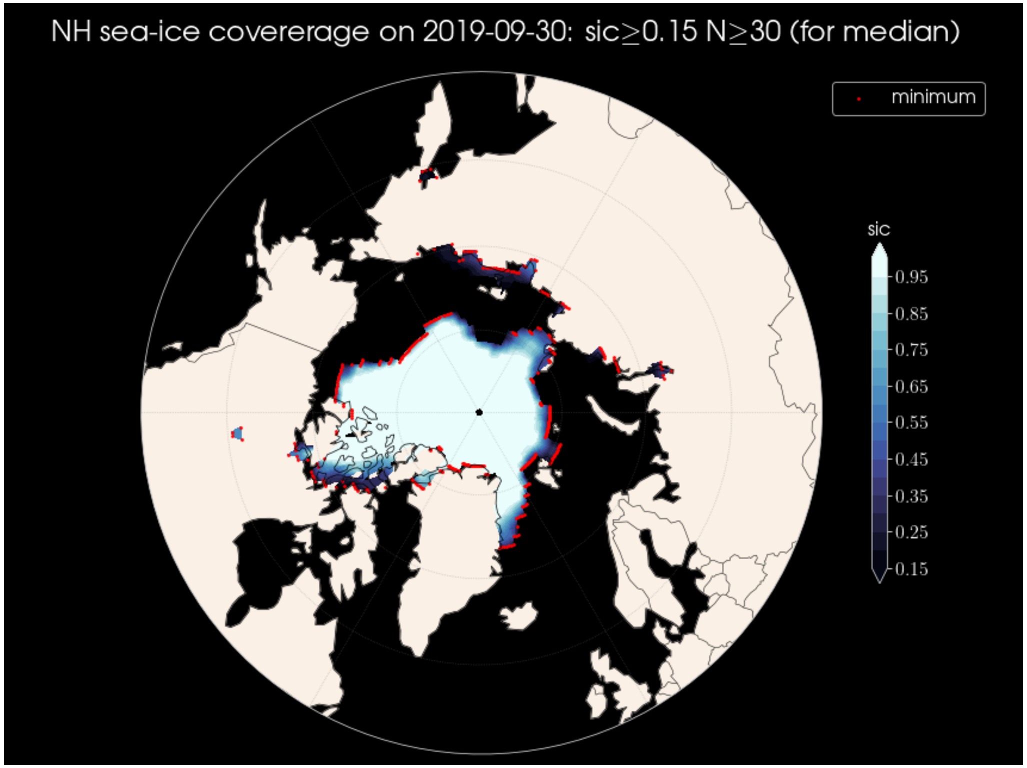
1. Developing a metric for the median sea-ice boundary

Method – Step 1

We calculate the median of all latitudinal minima from reanalysis



- We calculate the latitude of the monthly minimum sea ice concentration (SIC) ≥ 0.15 in **JRA-55 reanalysis** at all longitudes (points in red)
- Then we calculate the median value of these latitudes and do this for each month of the reanalysis over the whole record (1958-2019)

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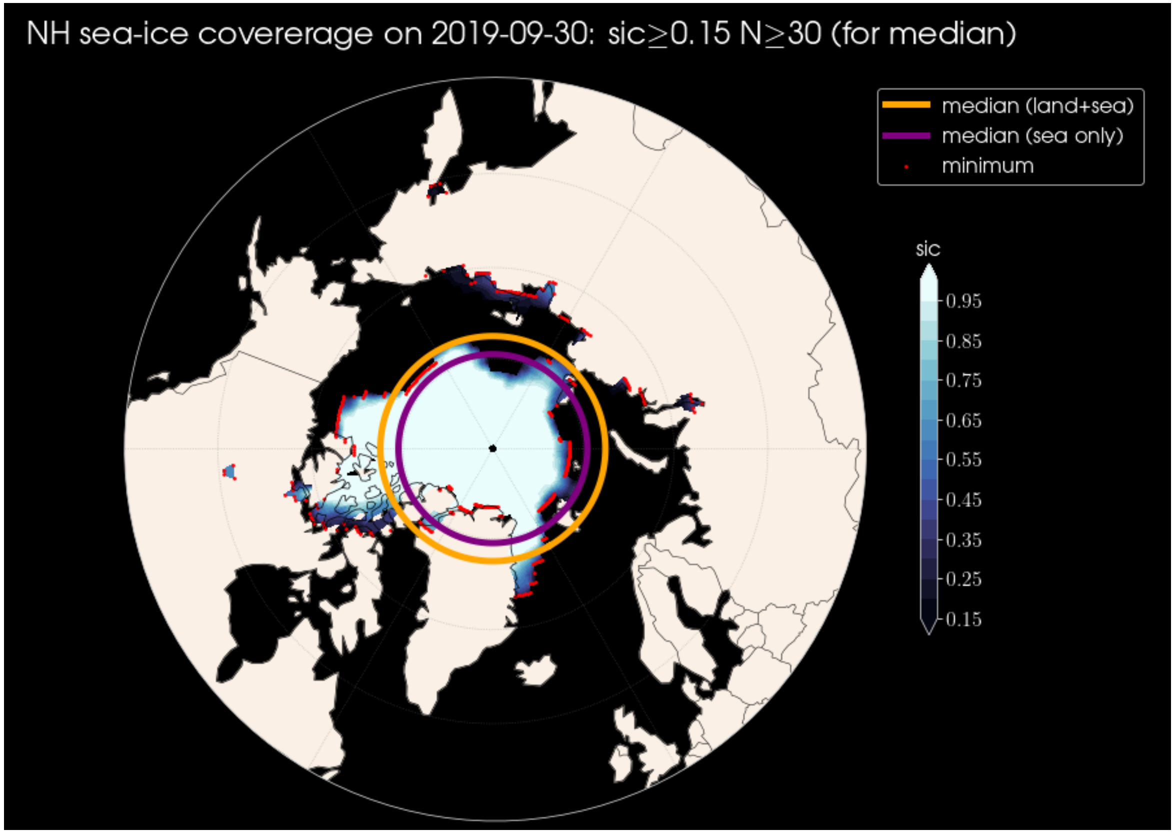
Results (Step 1)

We obtain the median sea-ice boundary centered at the North Pole



- If we do this for sea ice over open sea and for sea ice over land + sea (i.e. including lake ice) we get 2 different values for the median
- We repeat this for every month over the reanalysis period (1958-2019)

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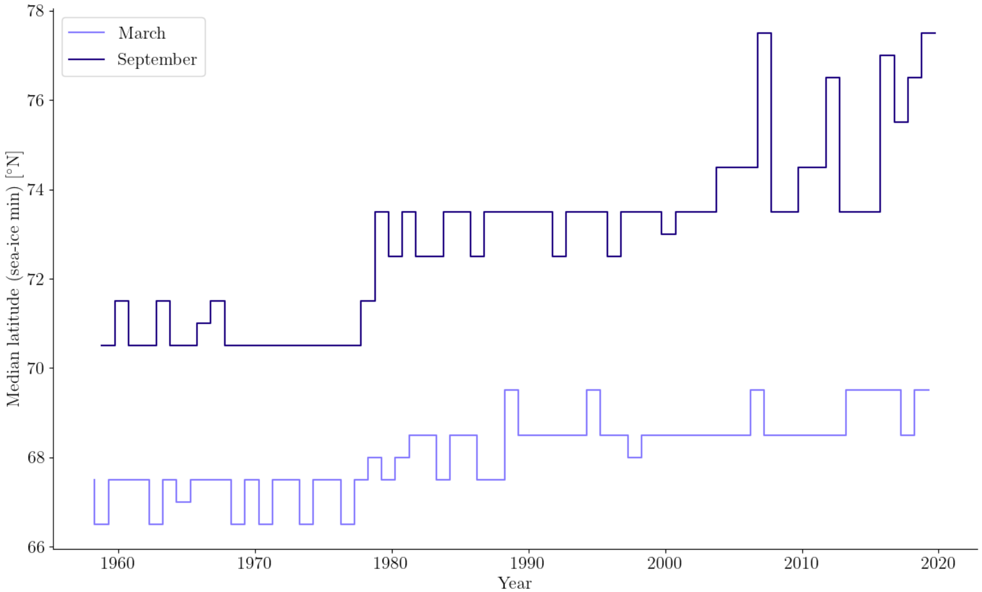
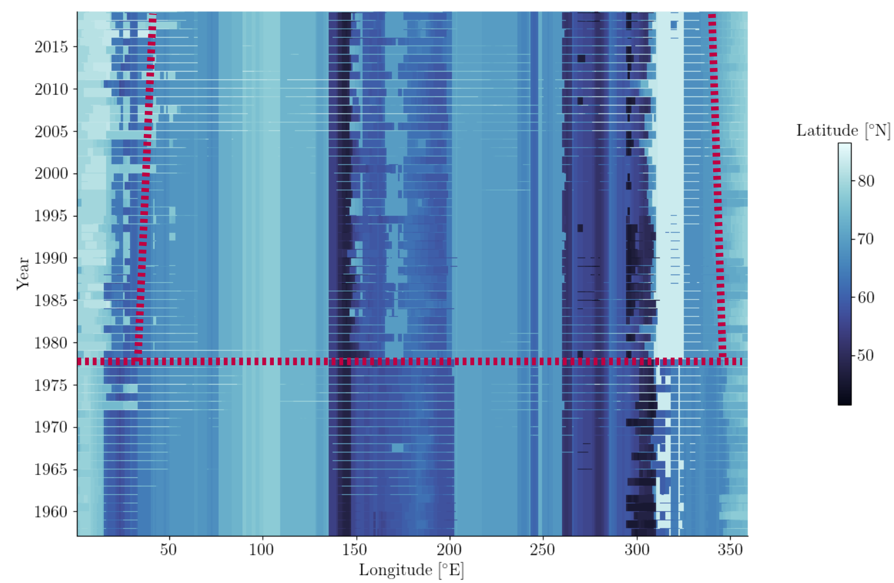
Results (Step 1)

March and September seasonal trends + geo-periodogram





Summer sea ice is retreating faster than winter sea ice* (NB: the balance of +ve and -ve feedbacks is currently asymmetric).

* which however is getting younger

Sea-ice minima geo-periodogram (one row per month) is showing regions of change: >1979, 0°-50°N, 150°-180°N, 280°-360°N

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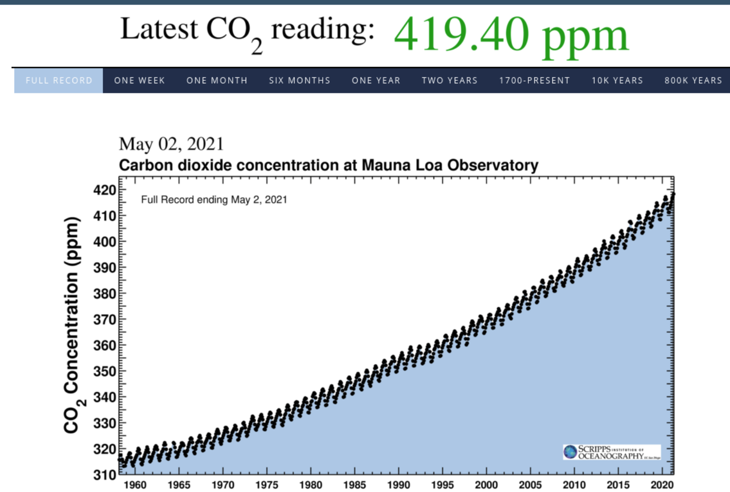
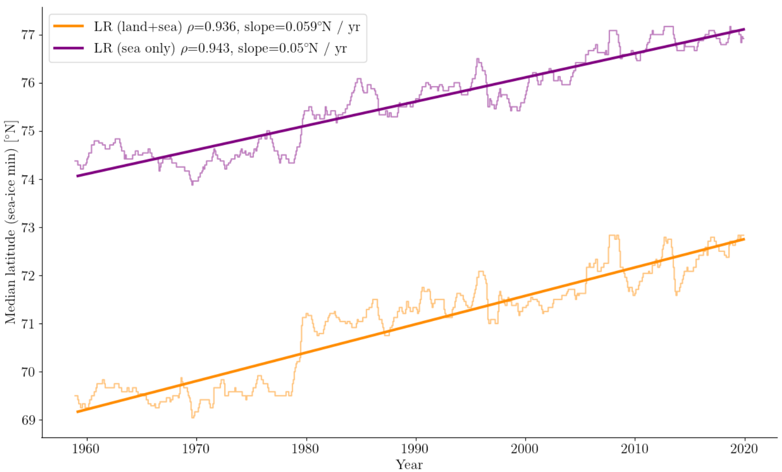
2. Relating the metric to the level of atmospheric CO_2

Method – Step 2

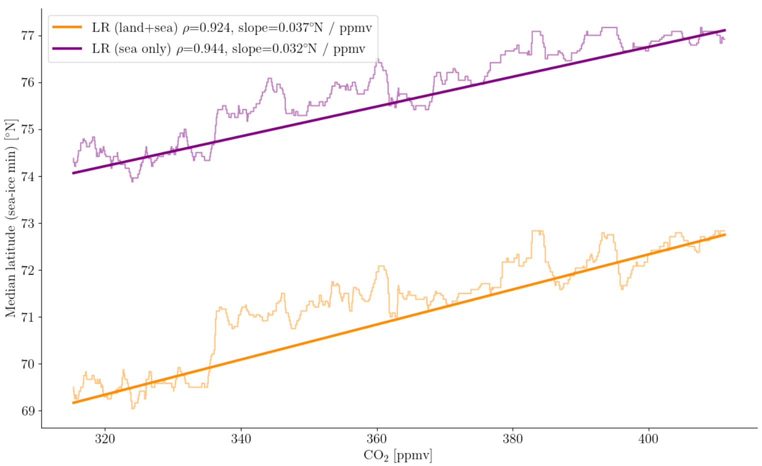
Keeling Curve Conversion of time ↔ CO_2



the current growth rate at Mauna Loa is 2.50 ± 0.26 ppmv /yr



Time ↔ CO_2



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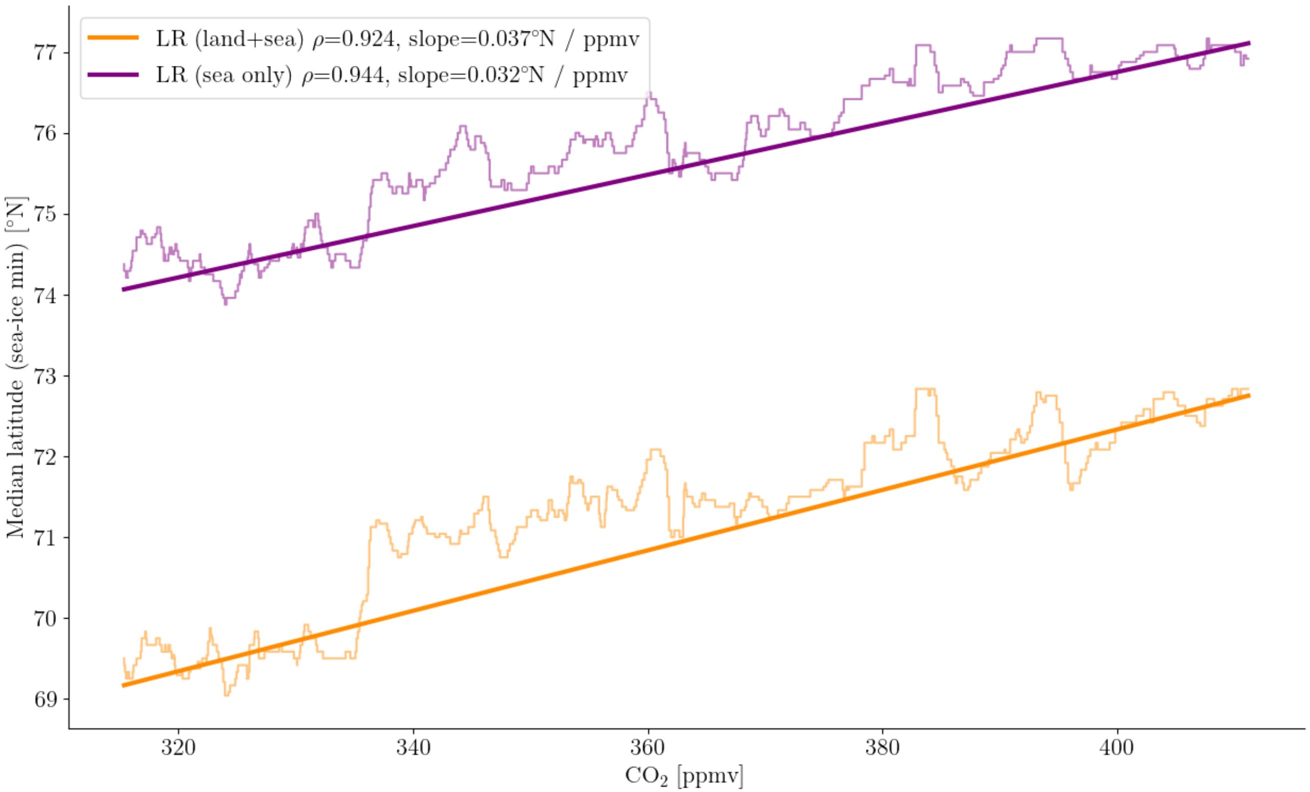
Results (Step 2)
Arctic sea ice retreat is (currently) linear



Locally linear estimate of Budyko's prediction

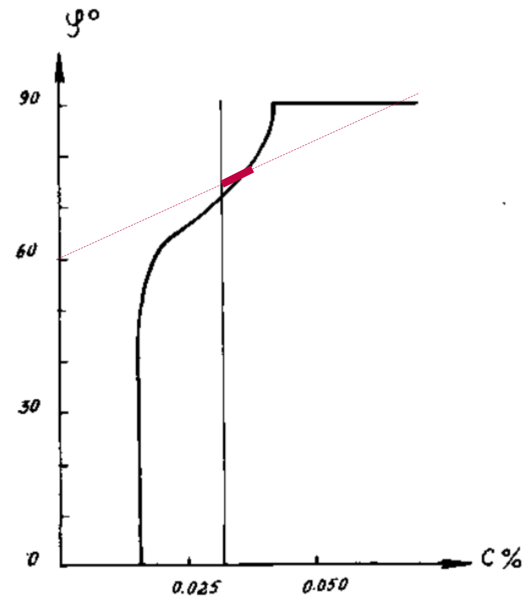


Fig. 3. Dependence of mean latitudinal ice cover boundary on carbon dioxide concentration.

CO_2 constitutes 0.042% by volume of the atmosphere (= 419.4 ppmv) or 3284 Gt CO_2 containing 895 Gt of Carbon

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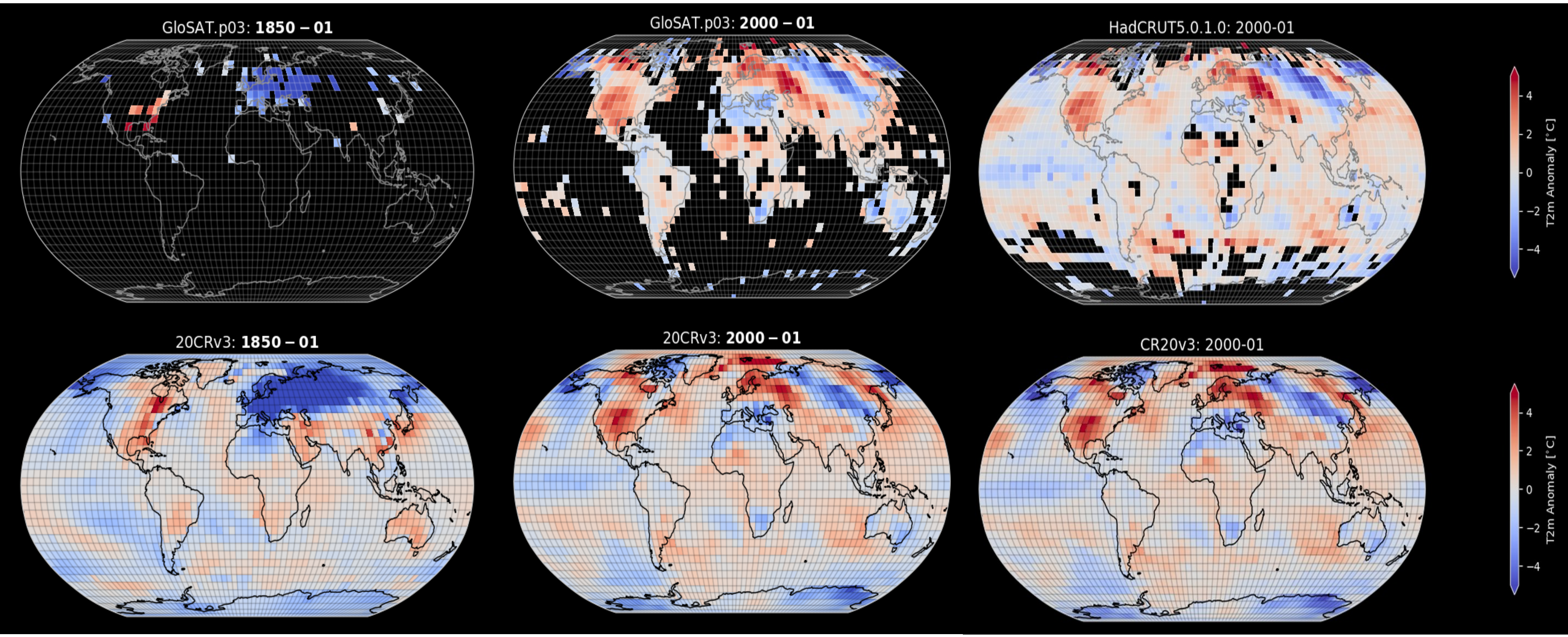
3. Assessing high latitude reanalysis

Reanalysis and Instrumental Measurements are Symbiotic

Pre-satellite era data reanalysis is constrained by land and sea observations

Land component **Land + sea**



Polar observations provide key constraints on models and more are needed

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Historical Data Rescue, Citizen Science & the Zooniverse

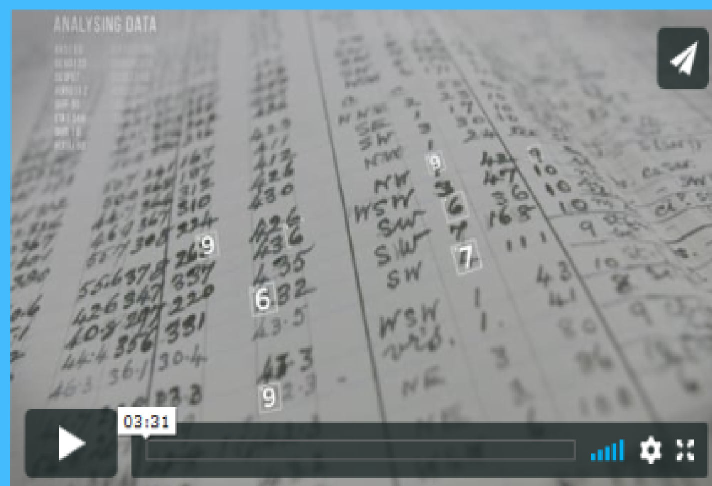
Help us build the time machine

PROJECTS ABOUT GET INVOLVED TALK BUILD A PROJECT NEWS NOTIFICATIONS MESSAGES PATTERNIZER

Southern Weather Discovery

ABOUT CLASSIFY TALK COLLECT RECENTS

Southern Weather Discovery Phase II - The Week it Snowed Everywhere!



FIELD GUIDE

Zooniverse

This phase of Southern Weather Discovery has some extra support from a **Microsoft AI for Earth grant.**

"The Week it Snowed Everywhere" dataset will help us improve understanding of extreme weather events within the context of long-term climate change.

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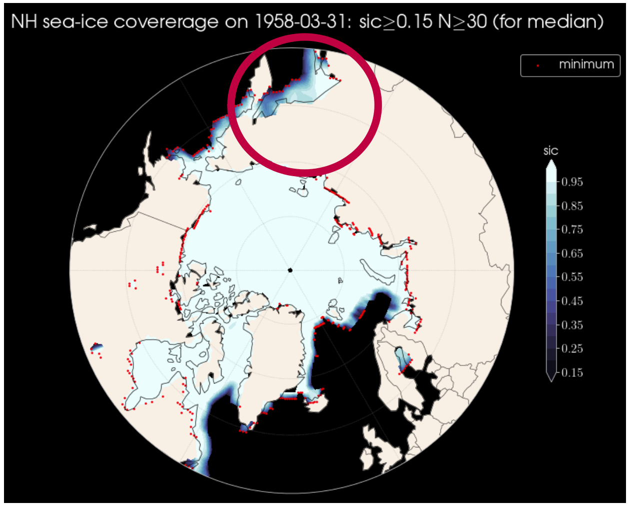
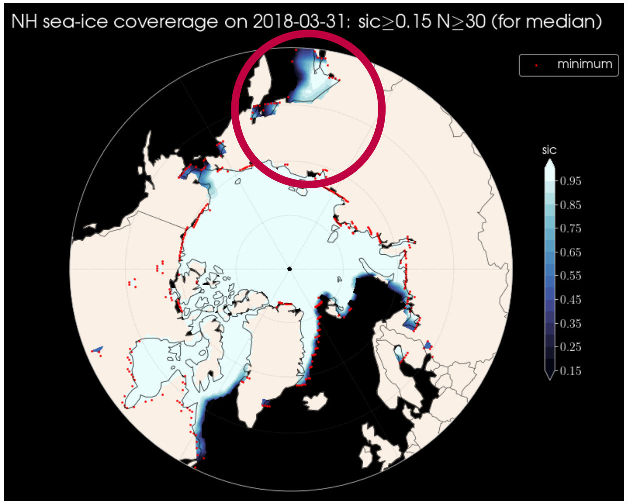
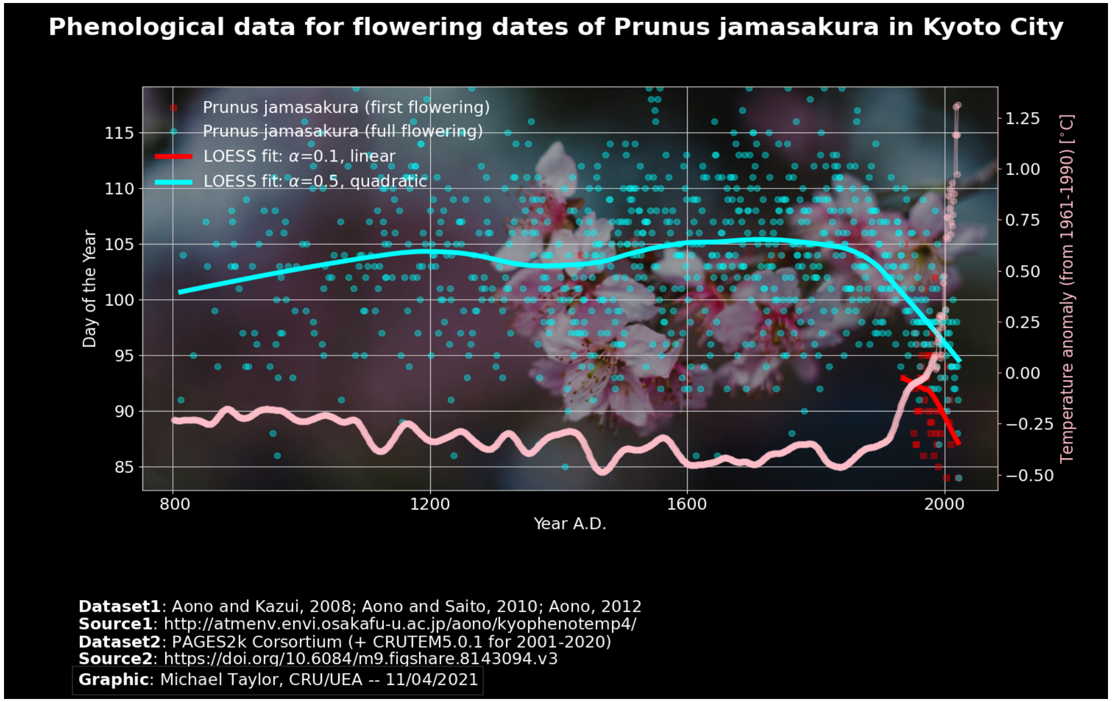
Historical Sea-Ice and Temperatures

Proxy reconstructions from the past help us understand present / future change







Providing key data points that are needed to constrain early reanalysis can help answer questions such as:

Q. Is regional sea-ice change responsible for earlier blooming of Japanese Cherry Blossom ?

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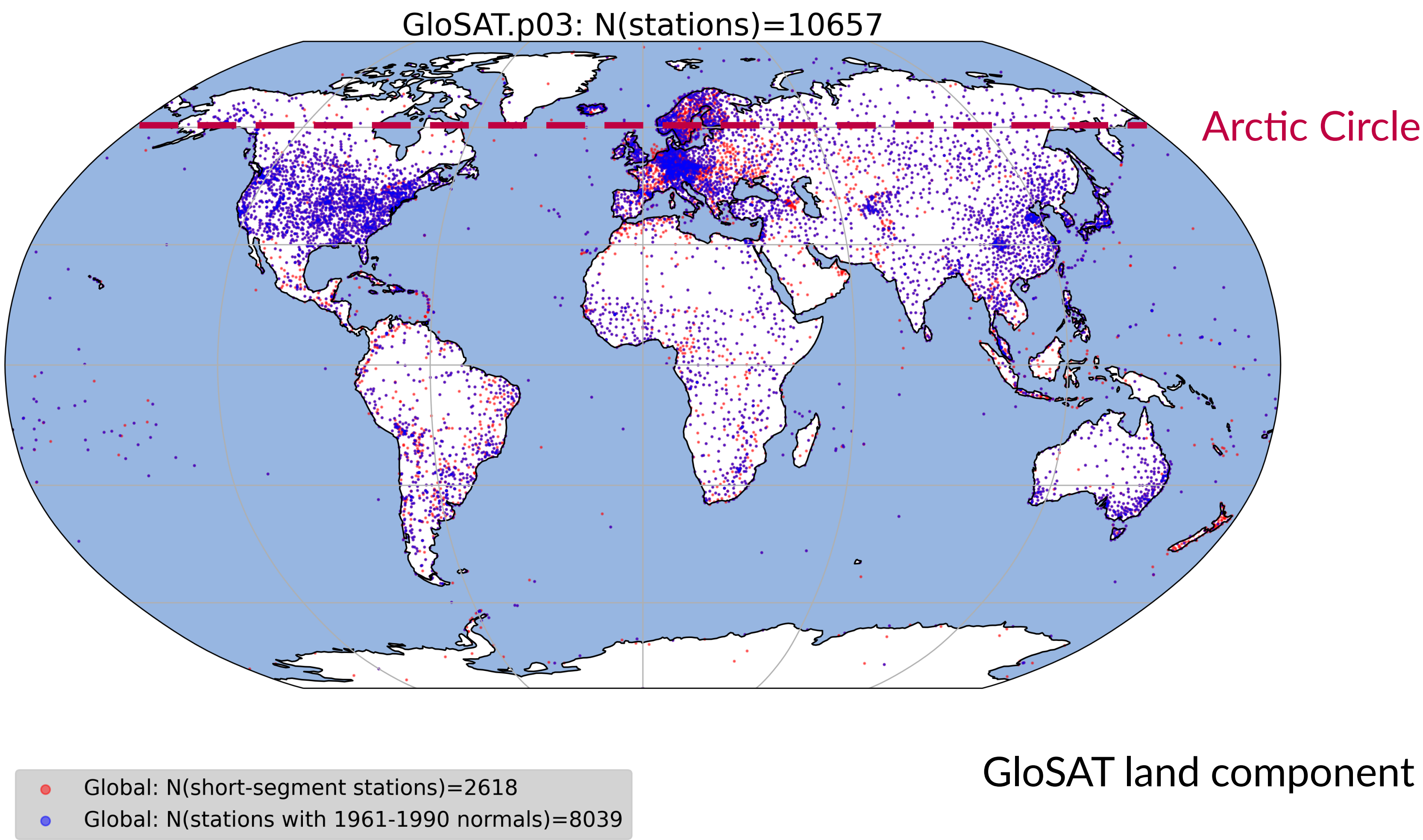
4. Best estimate Arctic temperature anomaly

GloSAT project glosat.org

Rescuing and homogenising land & sea surface air temperatures 1781-2021



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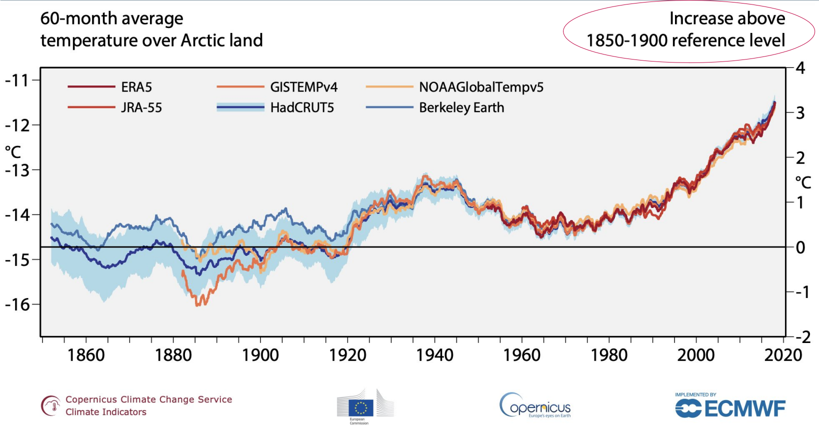
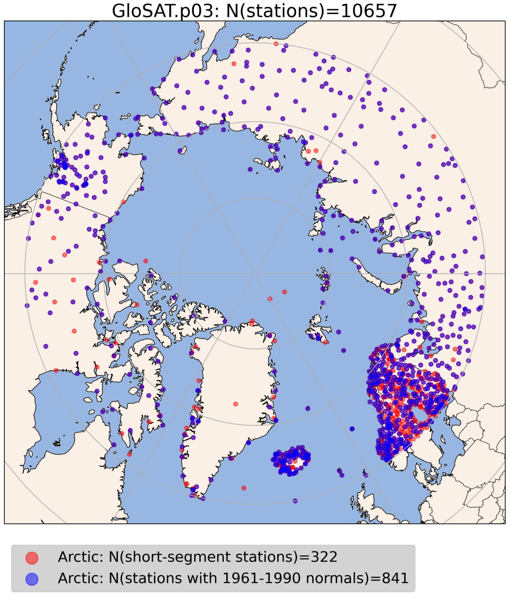
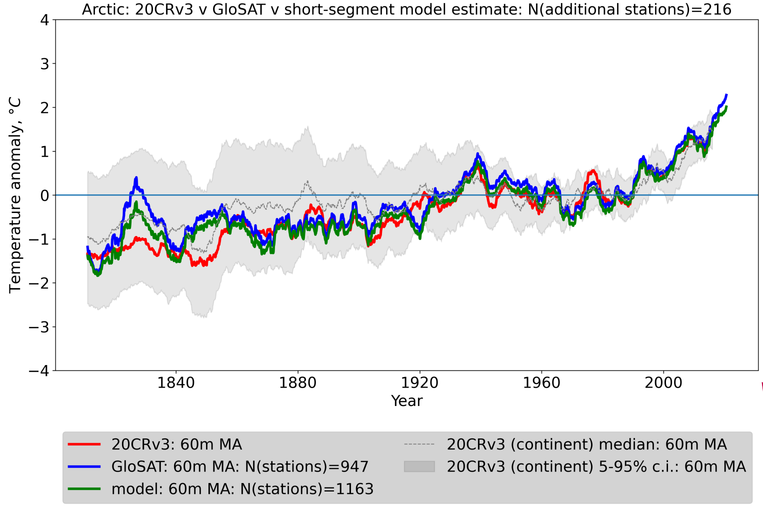
Arctic land surface air temperatures

How well do instrumental measurements and reanalysis agree ?



- Reanalysis is very sensitive to sea-ice uncertainty in the early data < 1900
- Evidence of +3°C warming since 1850
- Warming is impacting a lot of coastal Arctic ocean communities





temperature anomalies from 1961-1990 mean

Conclusions
Some thoughts

This brief study shows that **Mikhail Budyko had great foresight.** His 1972 analysis provides a **metric = the median monthly sea-ice boundary as a function of CO_2** - that can be used to help monitor trends in sea-ice in the Arctic.

The **poleward retreat** of sea-ice is currently **linear** and at a rate of 0.059 °N / yr or equivalently 0.037 °N / ppmv CO_2.

By using the Keeling curve or climate and paleo-model **forecasts of CO_2**, the median monthly sea-ice boundary regression fit can be used to make **predictions about the past or future extent of Arctic sea ice**.

This analysis is based on JRA-55 reanalysis which is driven by satellite retrievals of sea ice concentration. Comparison of instrumental observations of surface temperature with 20CRv3 reanalysis suggest that **more observations are needed to help constrain the reanalysis at high polar latitudes**. Citizen science efforts like Zooniverse are rescuing ship data from historical logbooks which helps in this regard.

Many thanks for listening

Data sources used:

PSL/NOAA
20CRv3 reanalysis 1806-2015:
https://portal.nersc.gov/project/20C_Reanalysis/
NCAR/UCAR & JMA
JRA-55 reanalysis data 1958-2019:
https://rda.ucar.edu/datasets/ds628.1
C3S CDS / ECMWF
ERA5 (incl. BE) reanalysis lake cover data 1950-2020:
https://cds.climate.copernicus.eu/#!/search?text=ERA5
UKMO Hadley Center
HadCRUT.5.0.1.0 and HadSST.3.1.0.0 anomaly data 1850-2020:
https://www.metoffice.gov.uk/hadobs
CRU/UEA & GloSAT
Ongoing updates to the global land surface air temperature instrumental record 1781-2021:
https://crudata.uea.ac.uk/cru/data/temperature/
https://www.glosat.org/

Codebase:
https://github.com/patternizer/budyko_calculation

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