


Observing the Climate System – now and in the future

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Chair, GCOS Steering Committee

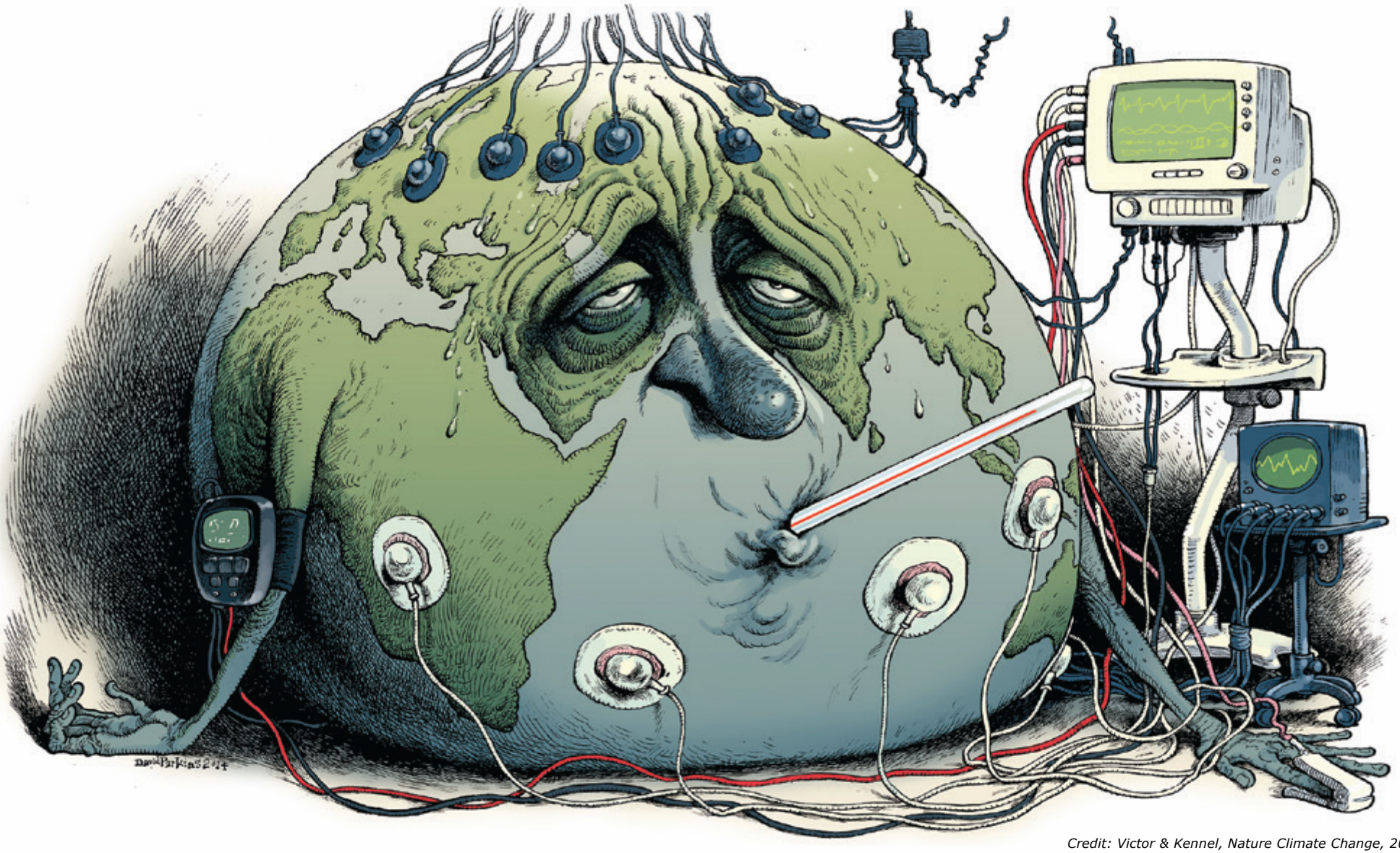
Dept. of Chemistry, Cambridge University &

Dept. of Meteorology Reading University

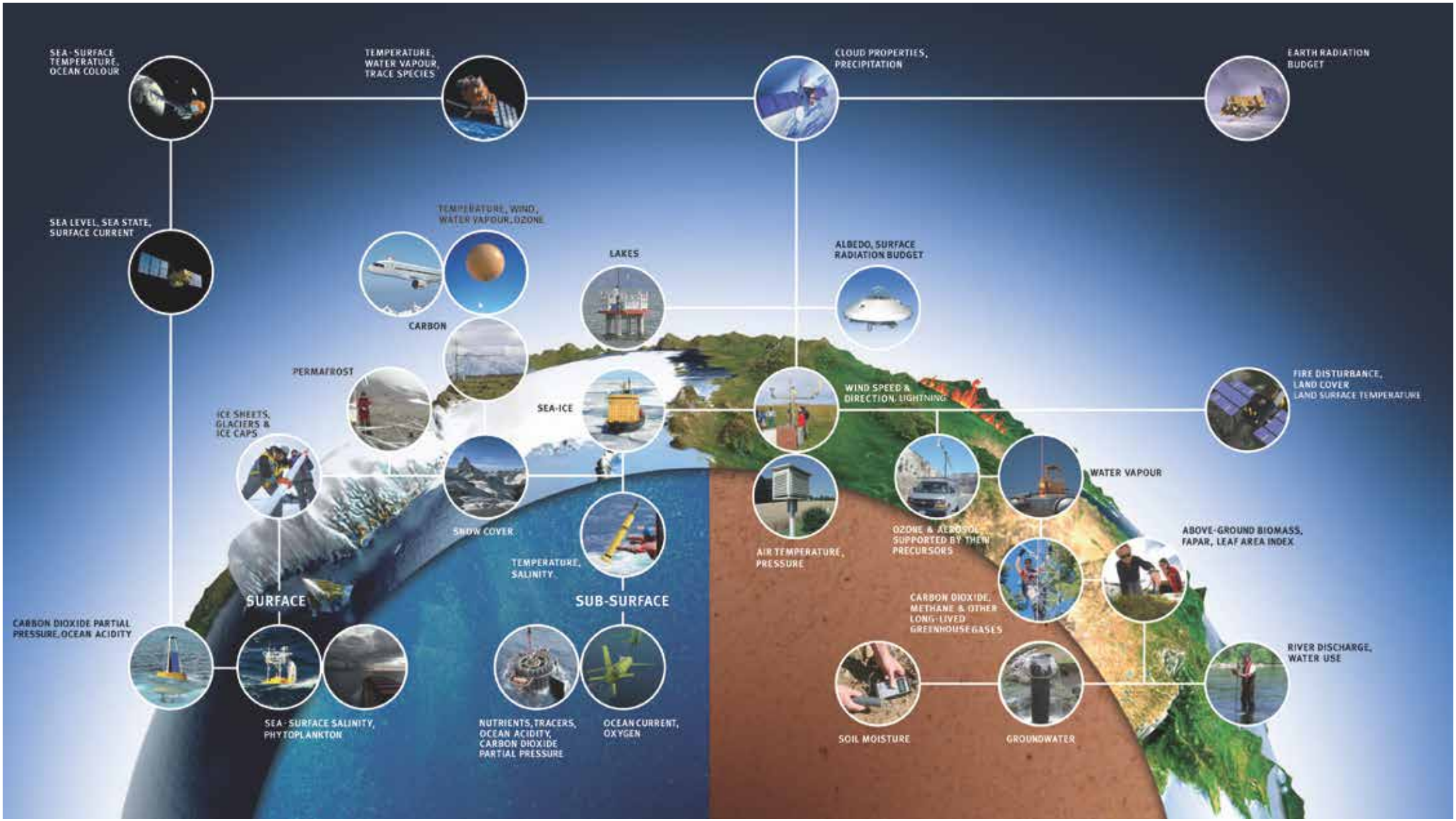
OBSERVING SYSTEM

KEEPING WATCH OVER OUR CLIMATI

International Science Council



Credit: Victor & Kennel, Nature Climate Change, 2014.


SEA-SURFACE TEMPERATURE, OCEAN COLOUR
TEMPERATURE, WATER VAPOUR, TRACE SPECIES
CLOUD PROPERTIES, PRECIPITATION
EARTH RADIATION BUDGET
SEA LEVEL, SEA STATE, SURFACE CURRENT
TEMPERATURE, WIND, WATER VAPOUR, OZONE
LAKES
ALBEDO, SURFACE RADIATION BUDGET
CARBON
PERMAFROST
SEA-ICE
WIND SPEED & DIRECTION, LIGHTNING
FIRE DISTURBANCE, LAND COVER LAND SURFACE TEMPERATURE
ICE SHEETS, GLACIERS & ICE CAPS
WATER VAPOUR
SNOW COVER
OZONE & AEROSOL, SUPPORTED BY THEIR PRECURSORS
ABOVE-GROUND BIOMASS, FAPAR, LEAF AREA INDEX
TEMPERATURE, SALINITY
AIR TEMPERATURE, PRESSURE
SURFACE
SUB-SURFACE
CARBON DIOXIDE, METHANE & OTHER LONG-LIVED GREENHOUSE GASES
CARBON DIOXIDE PARTIAL PRESSURE, OCEAN ACIDITY
RIVER DISCHARGE, WATER USE
SEA-SURFACE SALINITY, PHYTOPLANKTON
NUTRIENTS, TRACERS, OCEAN ACIDITY, CARBON DIOXIDE PARTIAL PRESSURE
OCEAN CURRENT, OXYGEN
SOIL MOISTURE
GROUNDWATER

Essential Climate Variables

ECV

Atmosphere

Surface

- Precipitation
- Pressure
- Radiation budget
- Temperature
- Water vapour
- Wind speed and direction

Upper-air

- Cloud properties
- Earth radiation budget
- Lightning
- Temperature
- Water vapour
- Wind speed and direction

Atmospheric Composition

- Aerosol and ozone precursors
- Aerosols properties
- Carbon dioxide, methane and other greenhouse gases
- Ozone

Ocean

Physical - Surface

- Ocean surface heat flux
- Sea ice
- Sea level
- Sea state
- Sea surface currents
- Sea surface salinity
- Sea surface stress
- Sea surface temperature

Physical - subsurface

- Subsurface currents
- Subsurface salinity
- Subsurface temperature

Biological/ecosystems

- Marine habitat properties
- Plankton

Biogeochemical

- Inorganic carbon
- Nitrous oxide
- Nutrients
- Ocean colour
- Oxygen
- Transient tracers

Land

Hydrosphere

- Groundwater
- Lakes
- River discharge

Cryosphere

- Glaciers
- Ice sheets and ice shelves
- Permafrost
- Snow

Anthroposphere

- Anthropogenic Greenhouse gas fluxes
- Anthropogenic water use

Biosphere

- Above-ground biomass
- Albedo
- Evaporation from land
- Fire
- Fraction of absorbed photosynthetically active radiation (FAPAR)
- Land cover
- Leaf area index
- Soil carbon
- Soil moisture
- Land surface temperature

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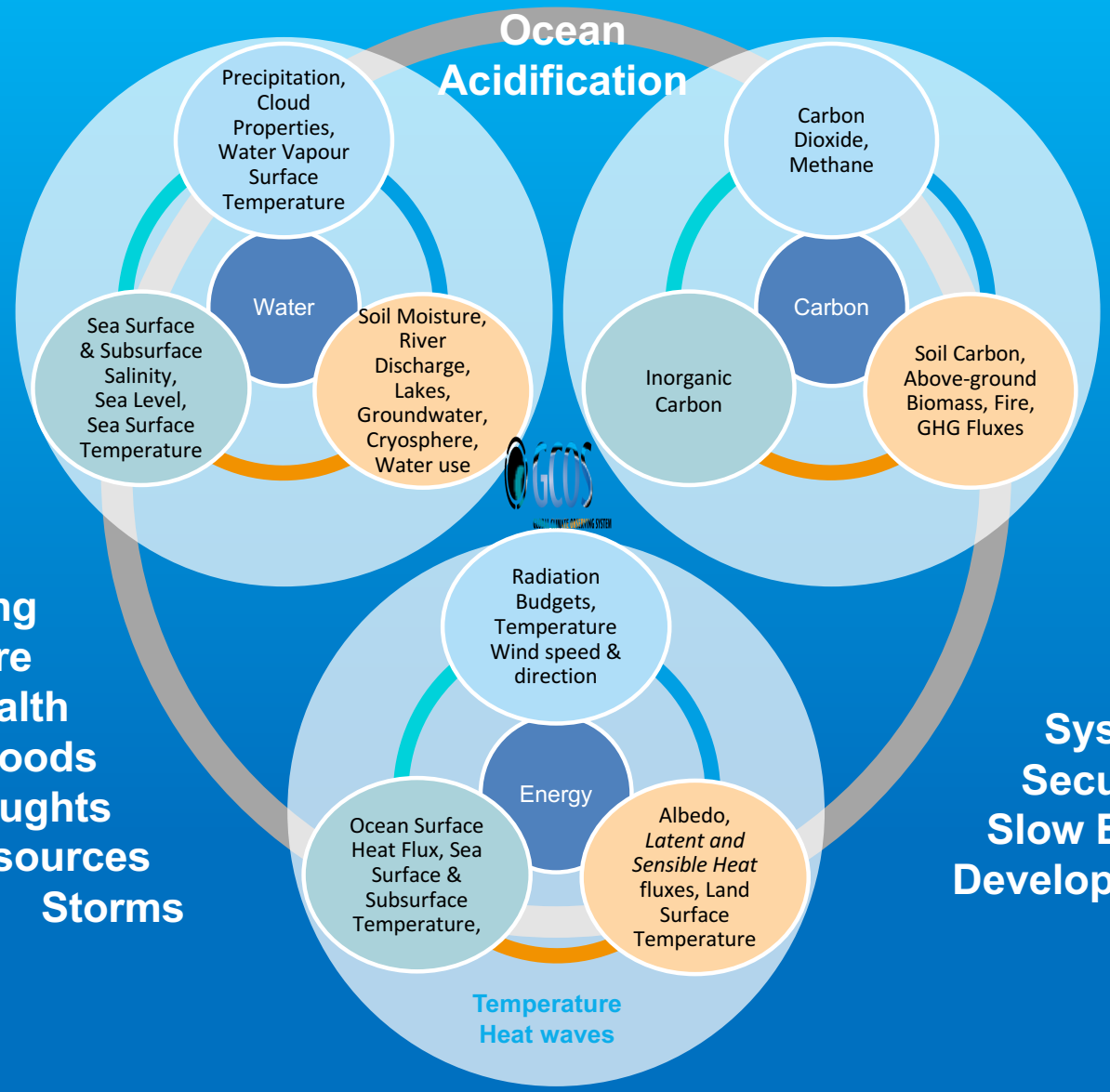
Understanding and monitoring Climate Cycles



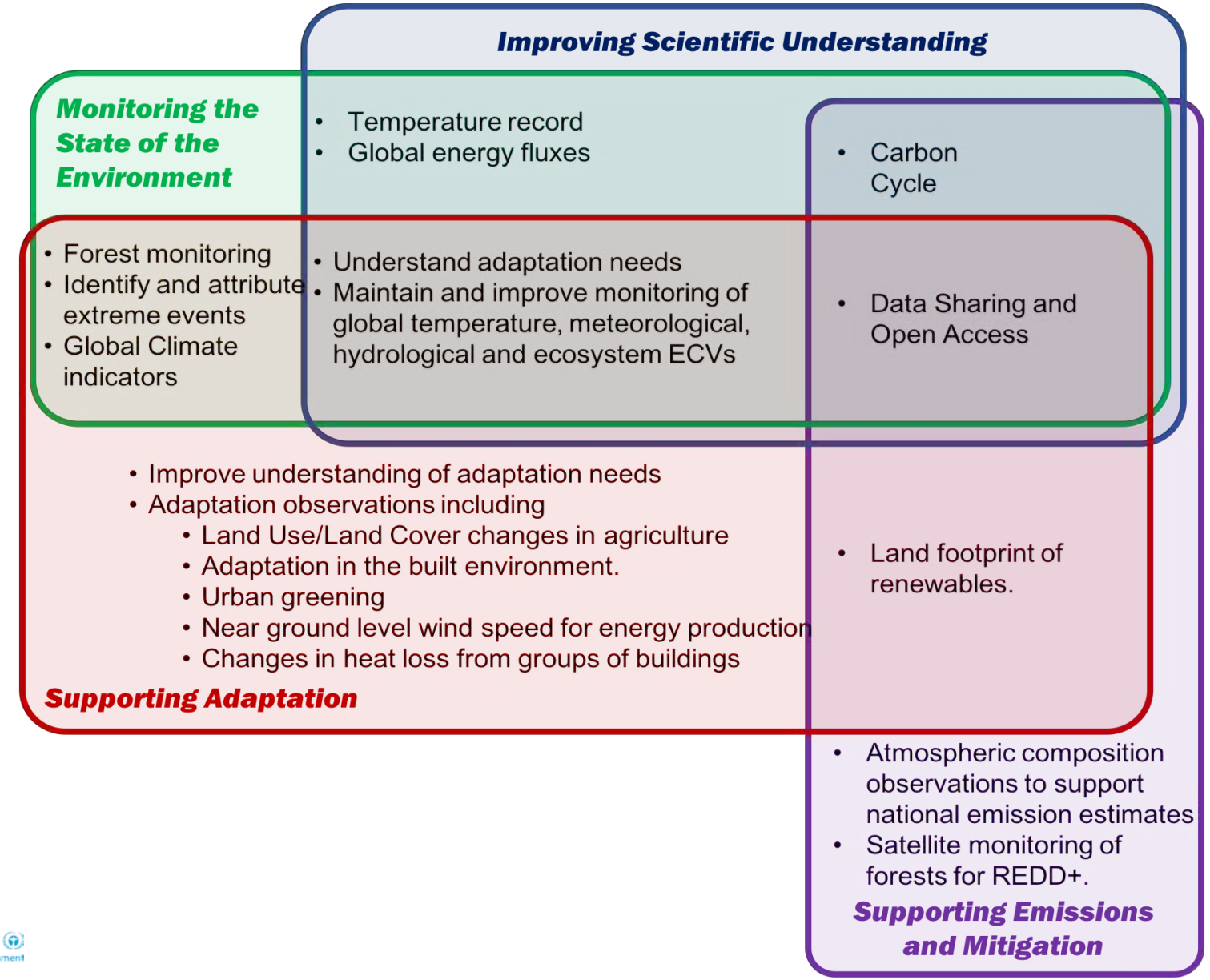
Sea Level Rise
Fisheries

Deforestation
Mitigation
Ecosystem Loss

Coral Bleaching
Agriculture
Human Health
Floods
Droughts
Water Resources
Storms

Systemic Risks
Security
Slow Economic Development

Monitoring contributing to the Paris Agreement & Global Stocktake



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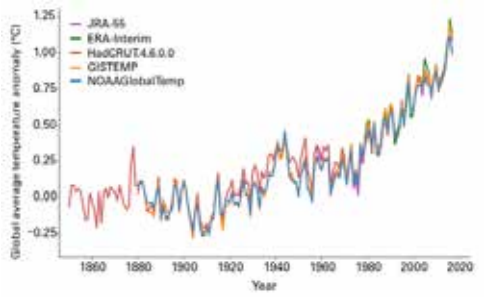
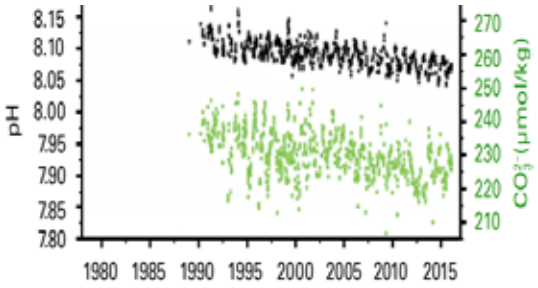
Mean Temperature



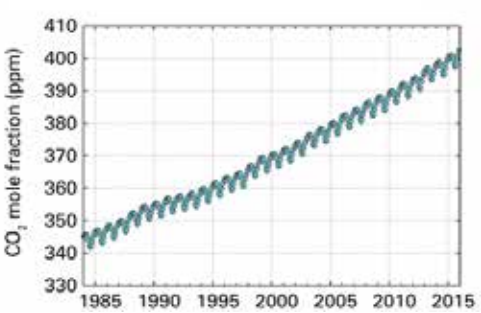
Global mean temperature anomalies, with respect to the 1850–1900 baseline, for the five global datasets (Source: UK Met Office Hadley Centre)

Ocean Acidity



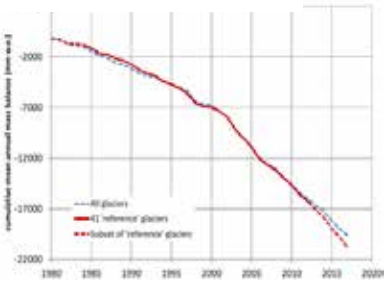
Trends in surface (< 50 m) ocean carbonate chemistry calculated from observations obtained at the Hawaii Ocean Timeseries (HOT) Program in the North Pacific over 1988–2015. Seawater pH (black points, primary y-axis) and carbonate ion concentration (green points, secondary y-axis). Ocean chemistry data were obtained from the Hawaii Ocean Timeseries Data Organization & Graphical System (HOT-DOGS). (Source: US National Oceanic and Atmospheric Administration (NOAA), Jewett and Romanou, 2017)

Atmospheric CO_2



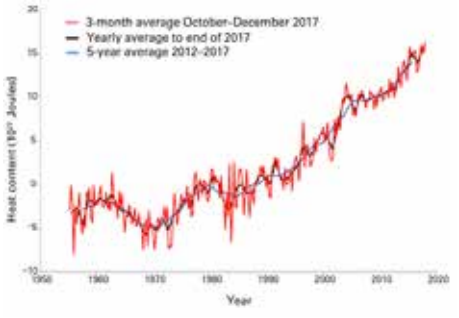
Globally averaged mole fraction (measure of concentration), from1984 to 2016, of CO2 in
parts per million (left), CH4 in parts per billion (middle) and N2O in parts per billion (right). The red line is the monthly mean mole fraction with the seasonal variations removed; the blue dots and line depict the monthly averages. (Source: WMO Global Atmosphere Watch)

Glacier Mass Balance



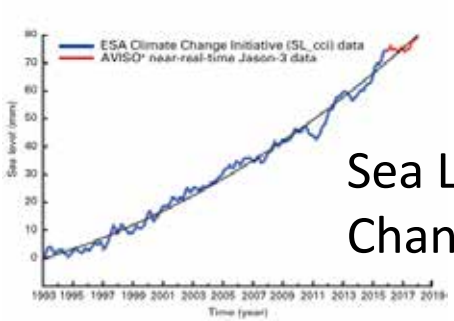
Mean cumulative mass balance of all reported glaciers (blue line) and the reference glaciers (red line). SOURCE: **world glacier monitoring service** http://wgms.ch/

Ocean Heat Content



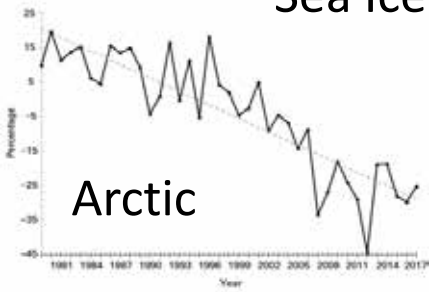
Global ocean heat content change (x 1022 J) for the 0–700 metre layer: three-monthly means (red), and annual (black) and 5-year (blue) running means, from the US National Oceanic and Atmospheric Administration (NOAA) dataset. (Source: prepared by WMO using data from NOAA National Centers for Environmental Information)

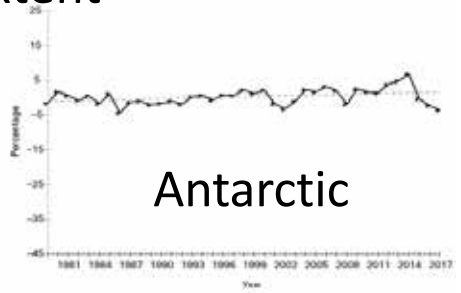
Sea Level Change



Global mean sea-level time series (with seasonal cycle removed), January 1993–January 2018, from satellite altimetry multi-missions. Data from AVISO
(Source: Collecte- Localisation-Satellite (CLS) – Laboratoire d'Etudes en Géophysique et Océanographie Spatiales (LEGOS))

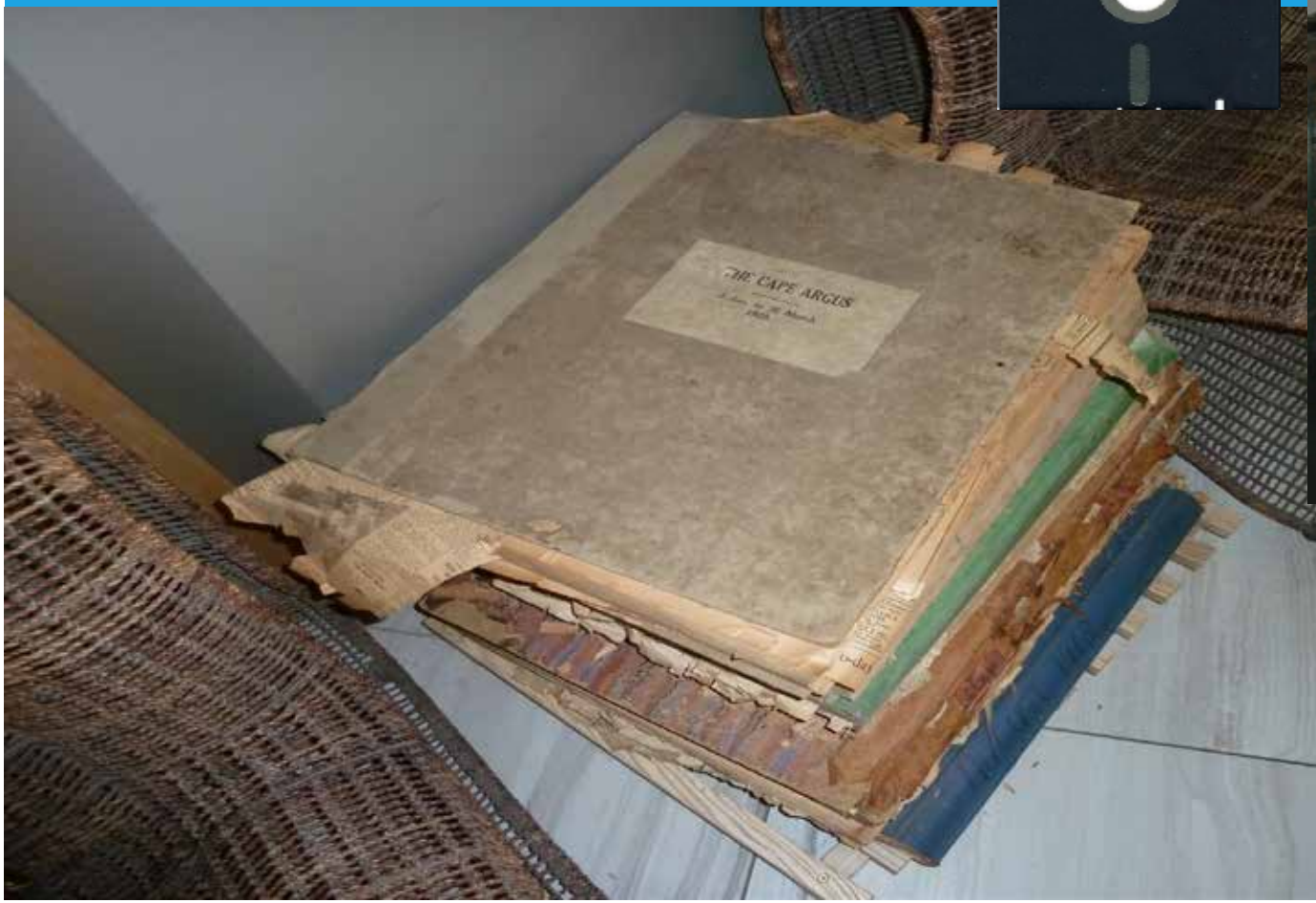
Sea Ice Extent



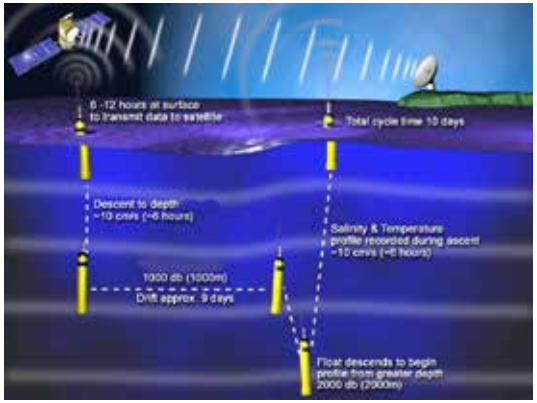


September sea-ice extent for the Arctic, and (right) September sea-ice extent for the Antarctic. Percentage of long-term average of the reference period 1981–2010 (Source: prepared by WMO using data from the US National Snow and Ice Data Center)

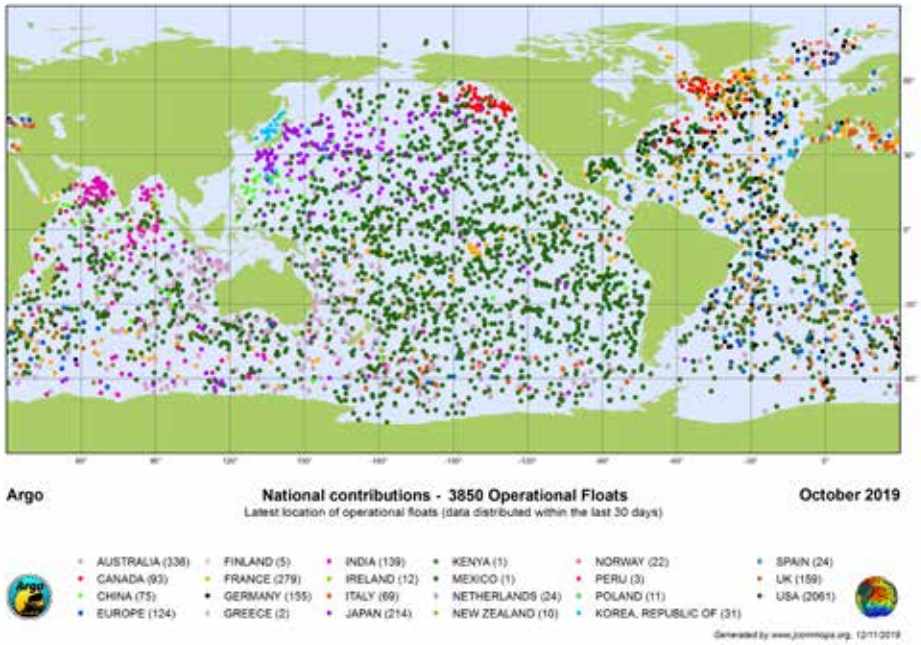
GCOS encourages Data Rescue

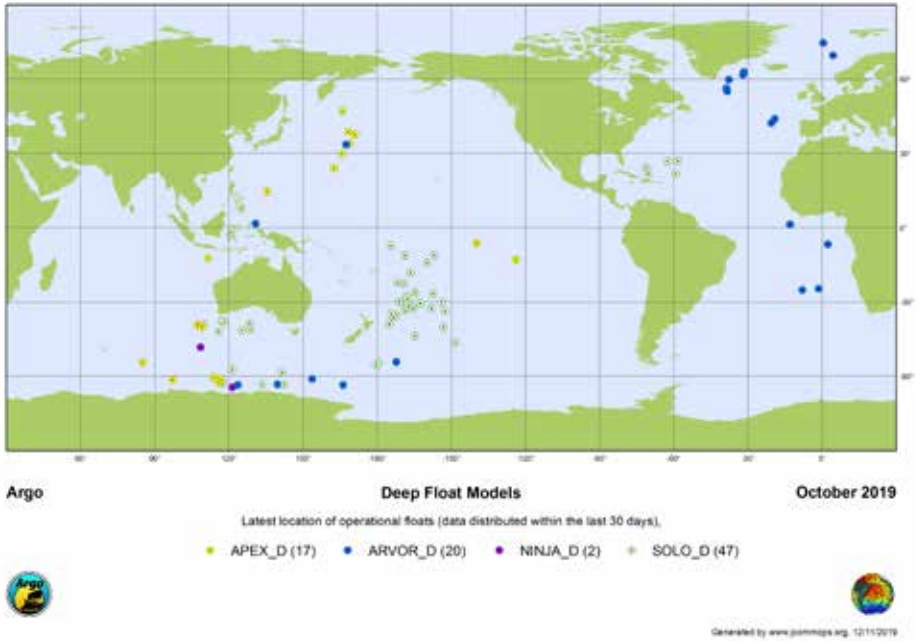


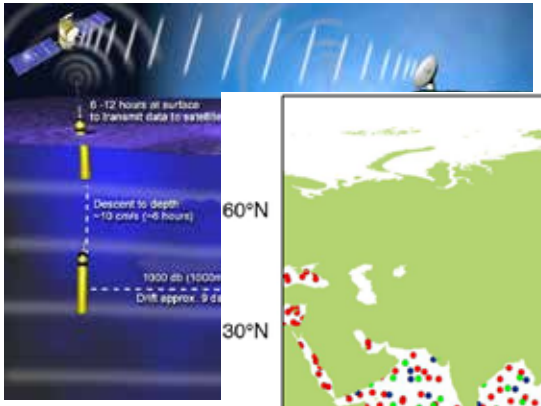
GCOS Cooperation Mechanism



Argo is one core network, with Deep Argo in pilot mode.



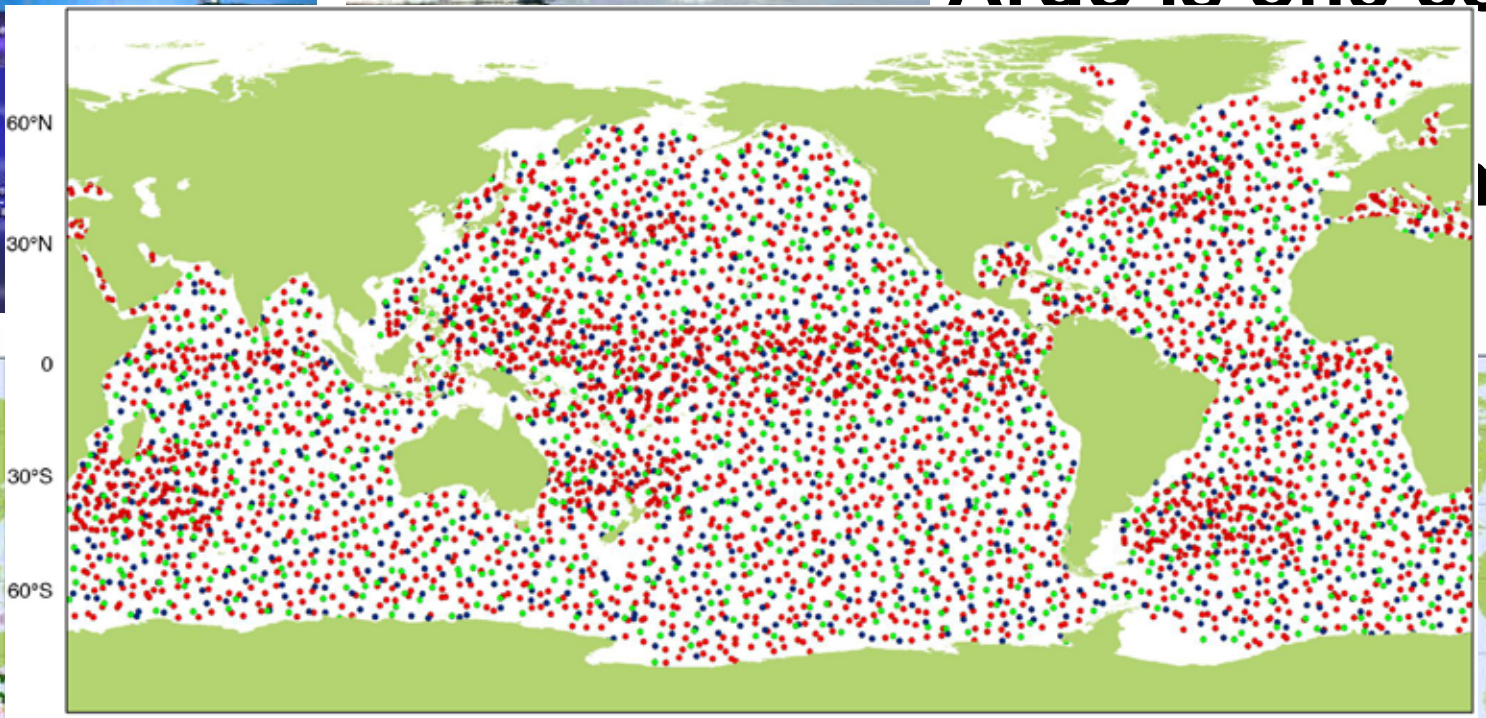




Argo is one core

Deep

node.



Argo 2020 Design: 4600 Floats

- Core Floats, 2350
- Deep Floats, 1250
- BGC Floats, 1000

Argo

October 2019

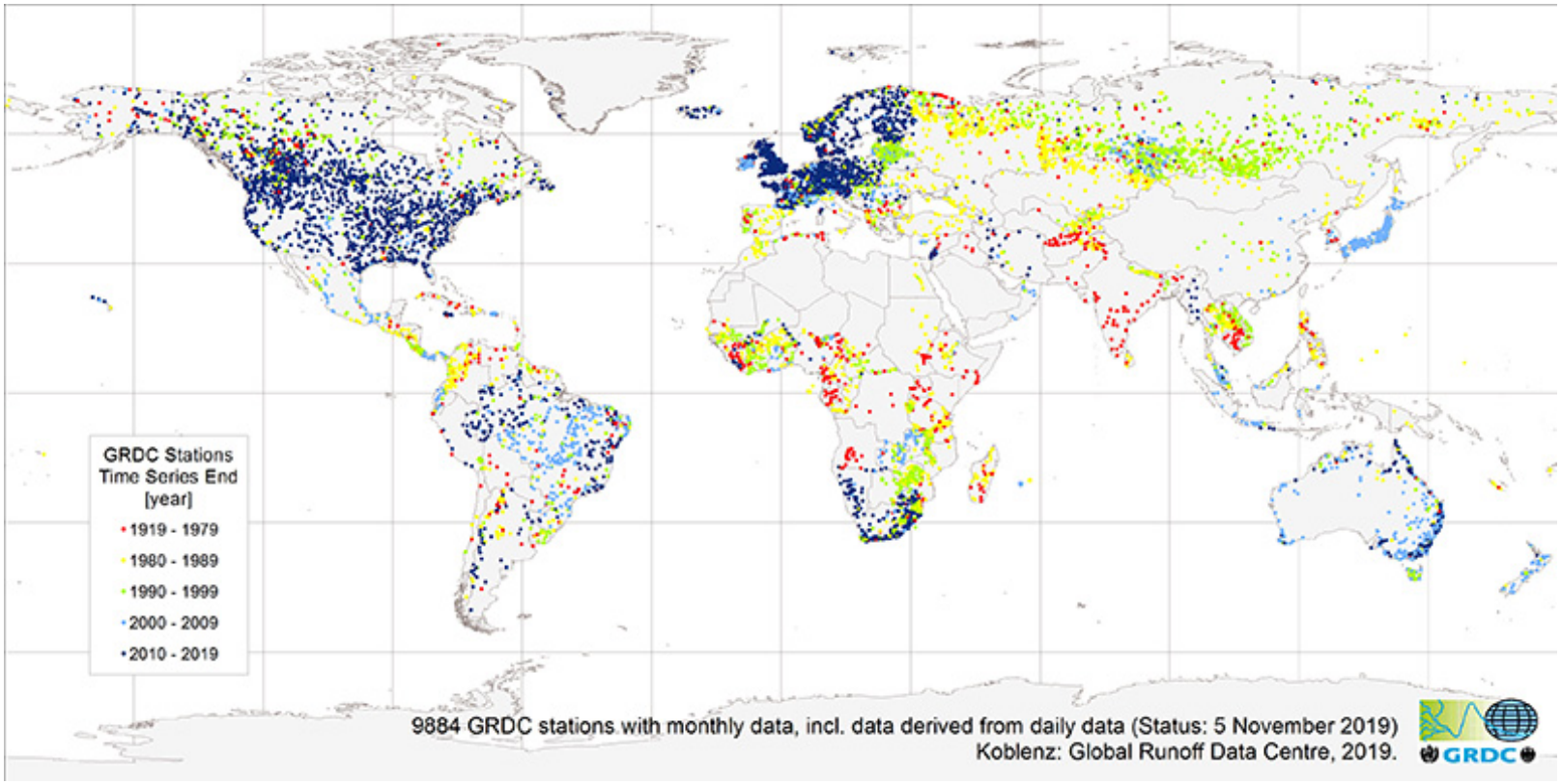
JCOMMOPS

AUSTRALIA (338) FINLAND (5) INDIA (139) KENYA (1) NORWAY (22) SPAIN (24)
CANADA (93) FRANCE (279) IRELAND (12) MEXICO (1) PERU (3) UK (159)
CHINA (75) GERMANY (155) ITALY (69) NETHERLANDS (24) POLAND (11) USA (2061)
EUROPE (124) GREECE (2) JAPAN (214) NEW ZEALAND (10) KOREA, REPUBLIC OF (31)

APEX_D (17) ARVOR_D (20) NINJA_D (2) SOLO_D (47)

Global River Discharge Data

- While river discharge is measured, in some parts of the world river discharge data is not routinely exchanged
- Measurements and data exchange are coordinated internationally by WMO
- The data is held by the Global Runoff Data Centre (GRDC) in Koblenz, Germany



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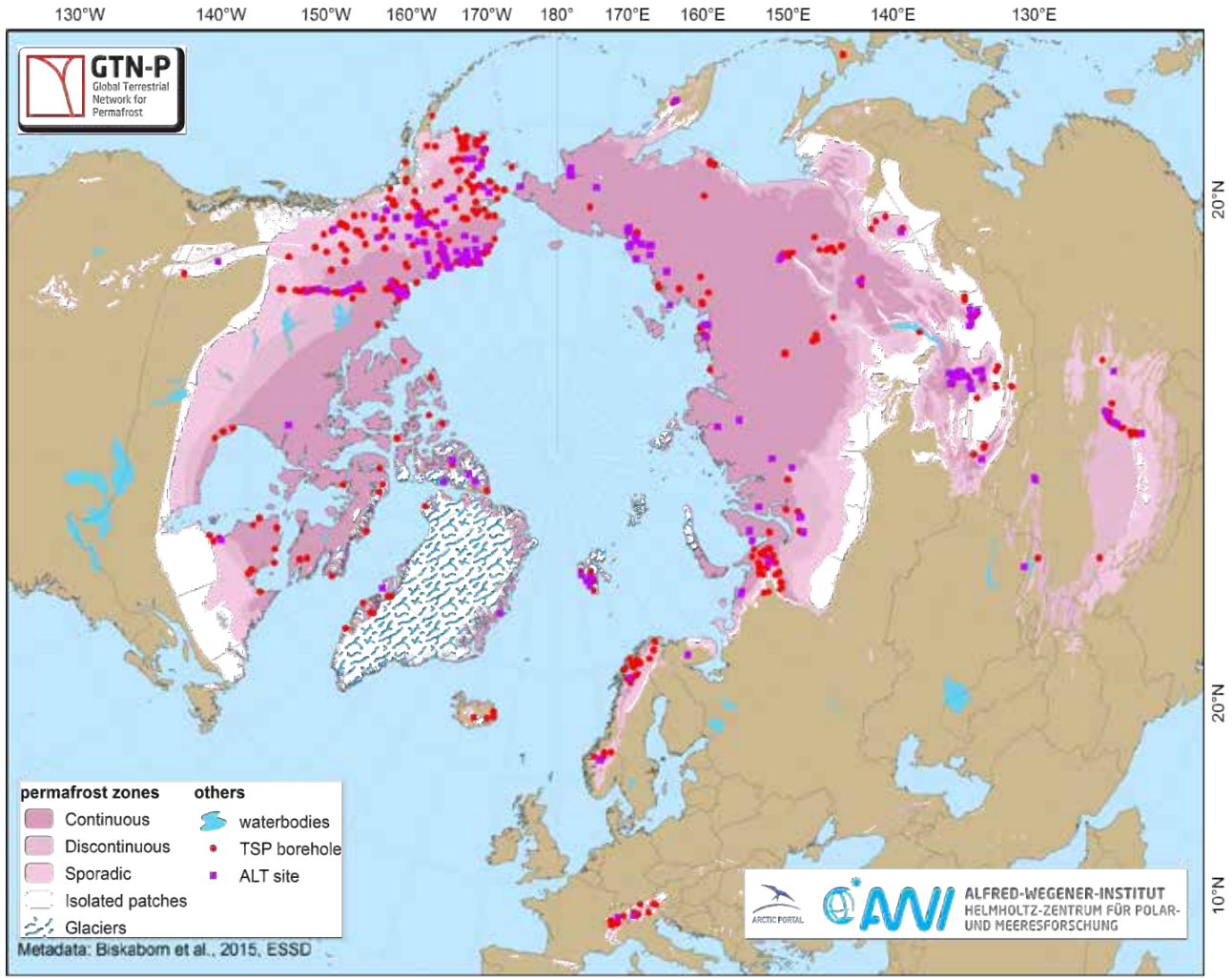
Arctic Permafrost Monitoring



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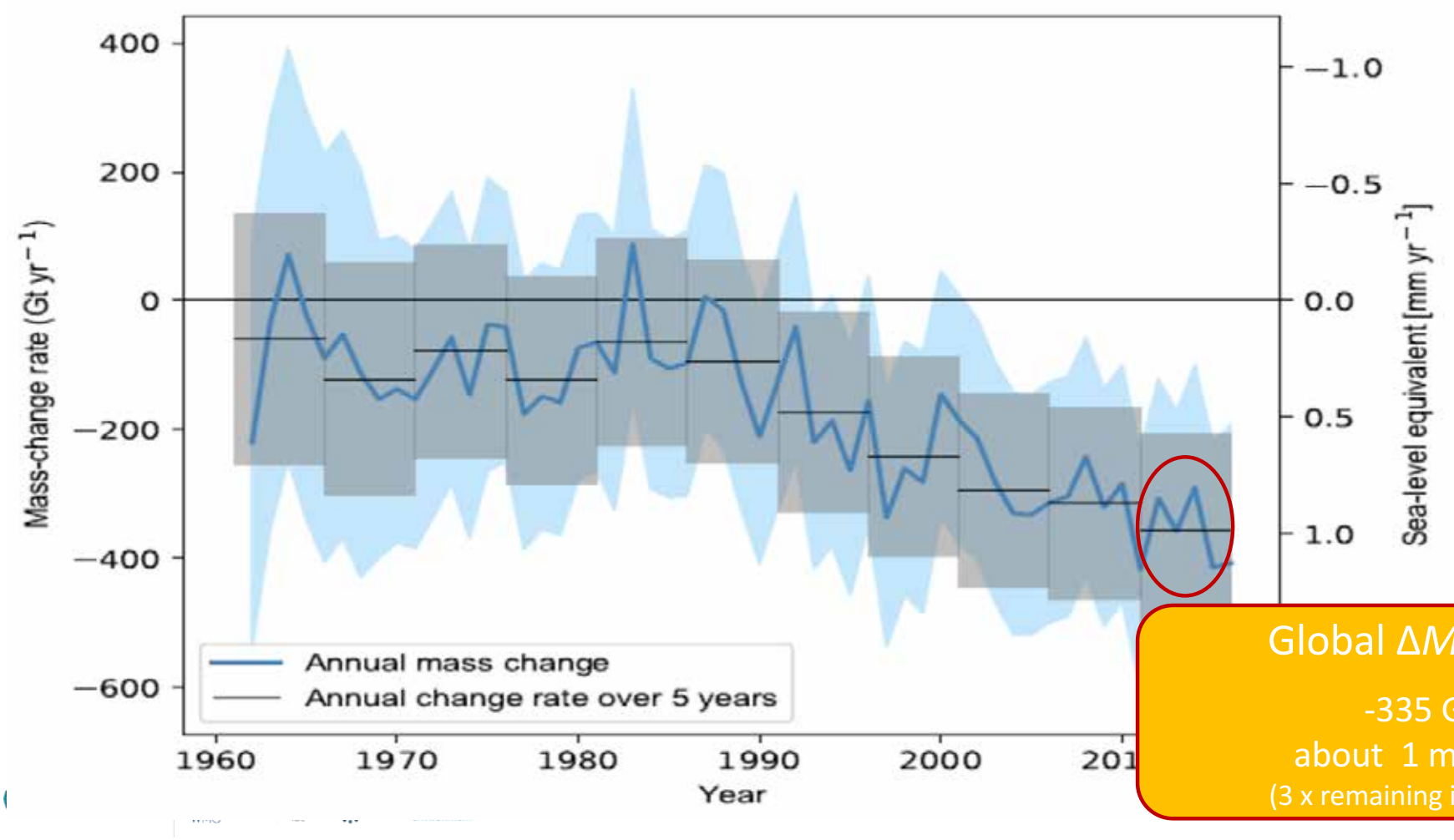
Glaciers distinct from the Greenland & Antarctic Ice Sheets

215,000 glaciers · 158,000 km^3 · 0.32 m potential SLE

Farinotti et al. (2019), Nature Geoscience

www.swisseduc.ch/glaciers/

Annual glacier contributions to sea-level rise 1961-2016

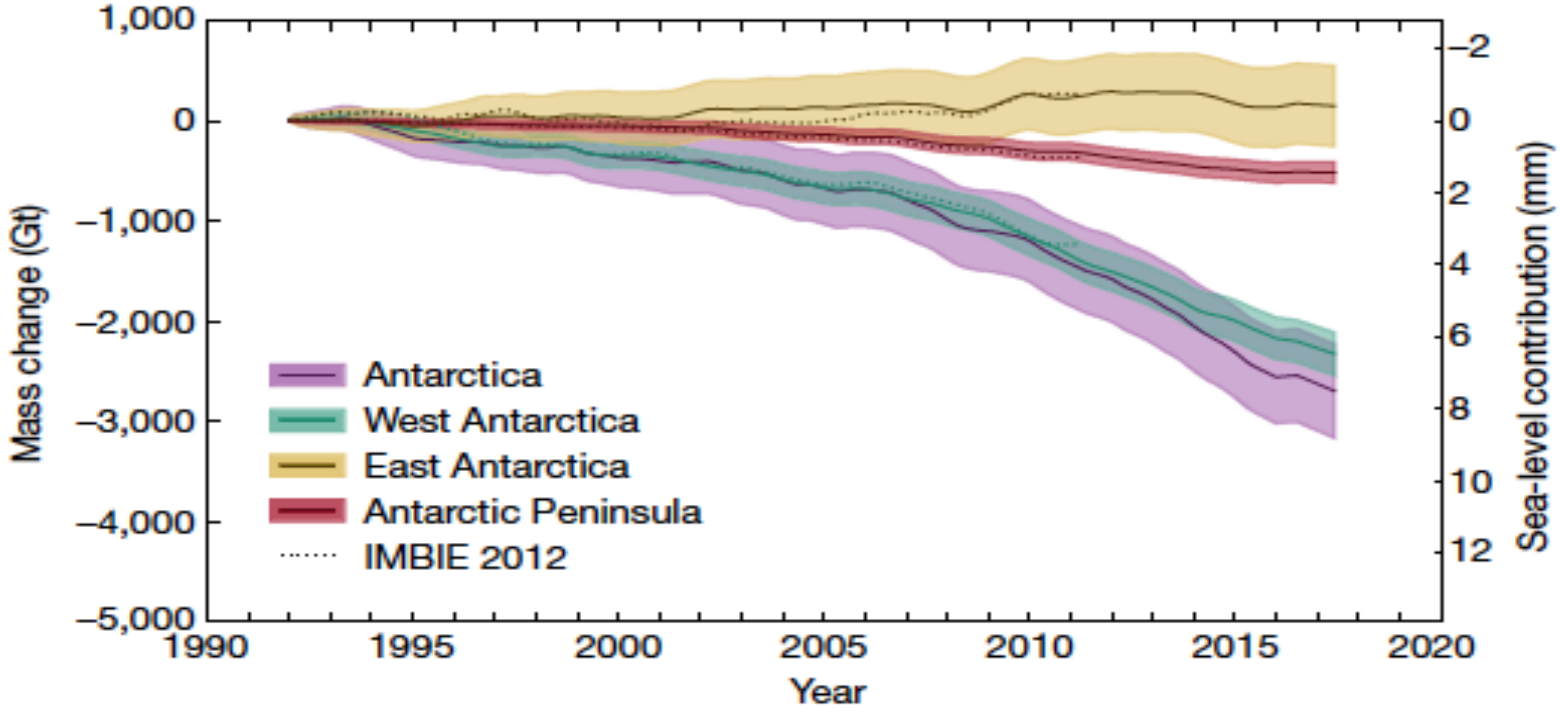


Global Δ*M 2011-16*:

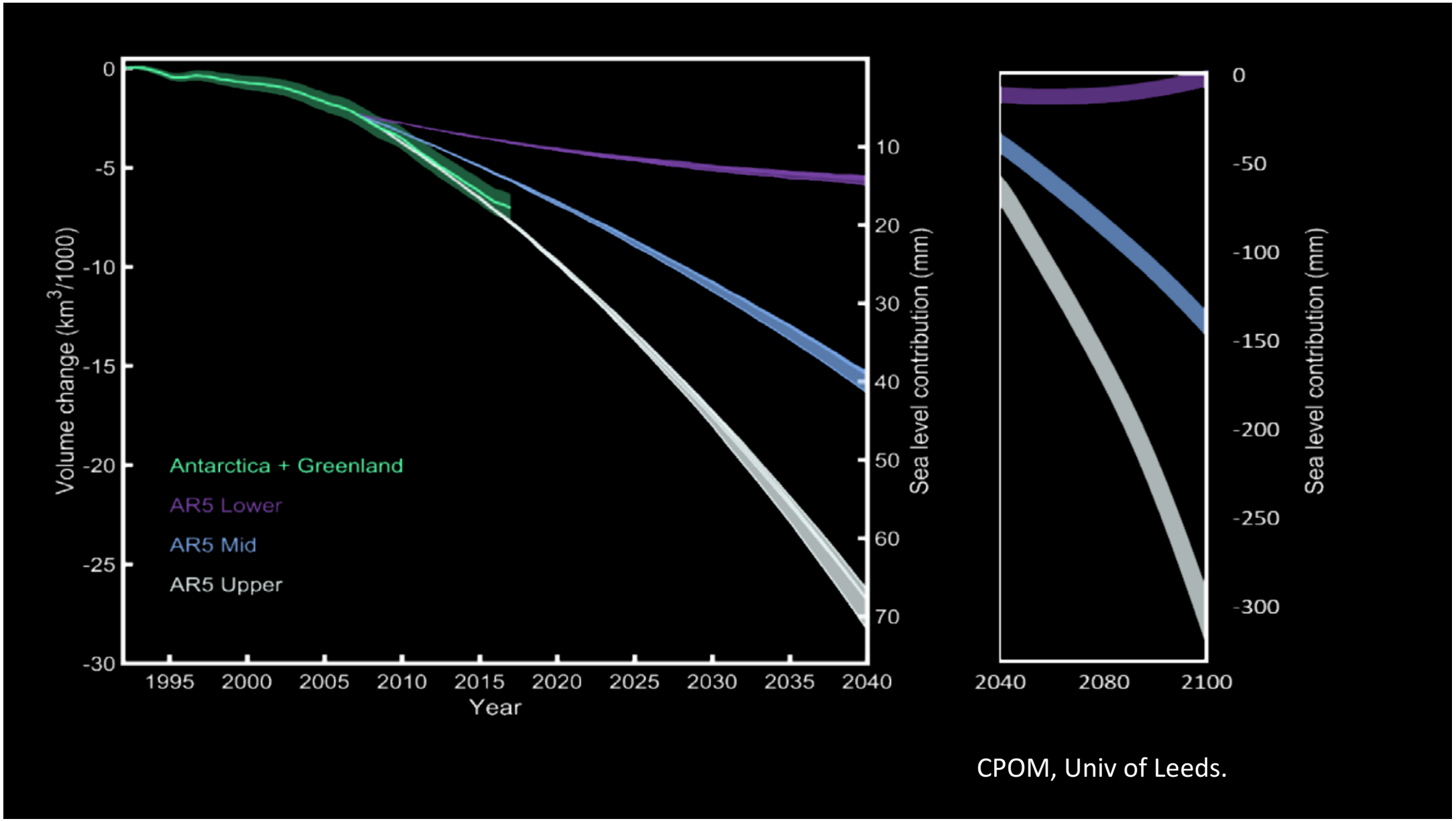
-335 Gt yr^{-1}

about 1 mm SLE yr^{-1}

(3 x remaining ice of the Alps)

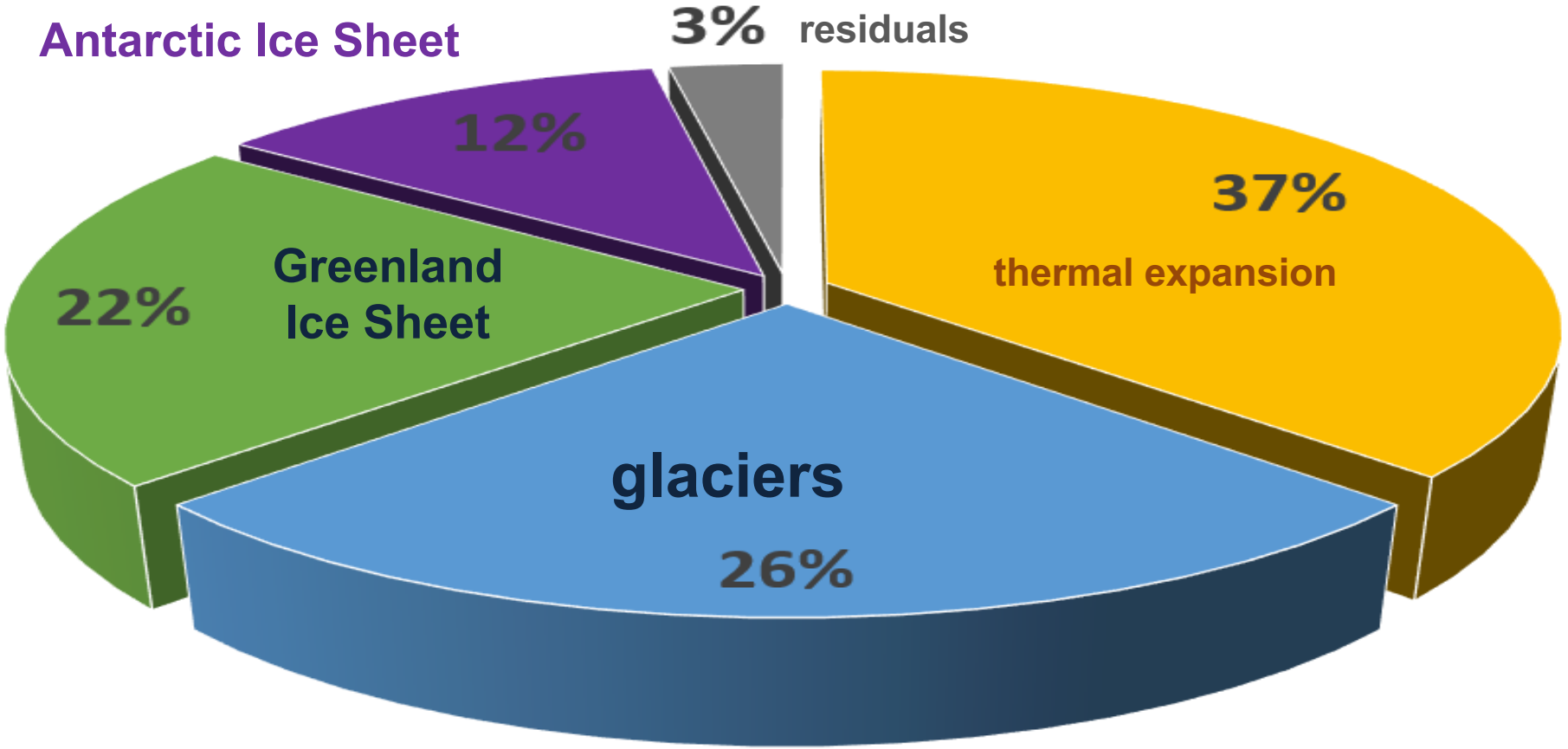


Shepherd et al,. *Nature*, June 2018.

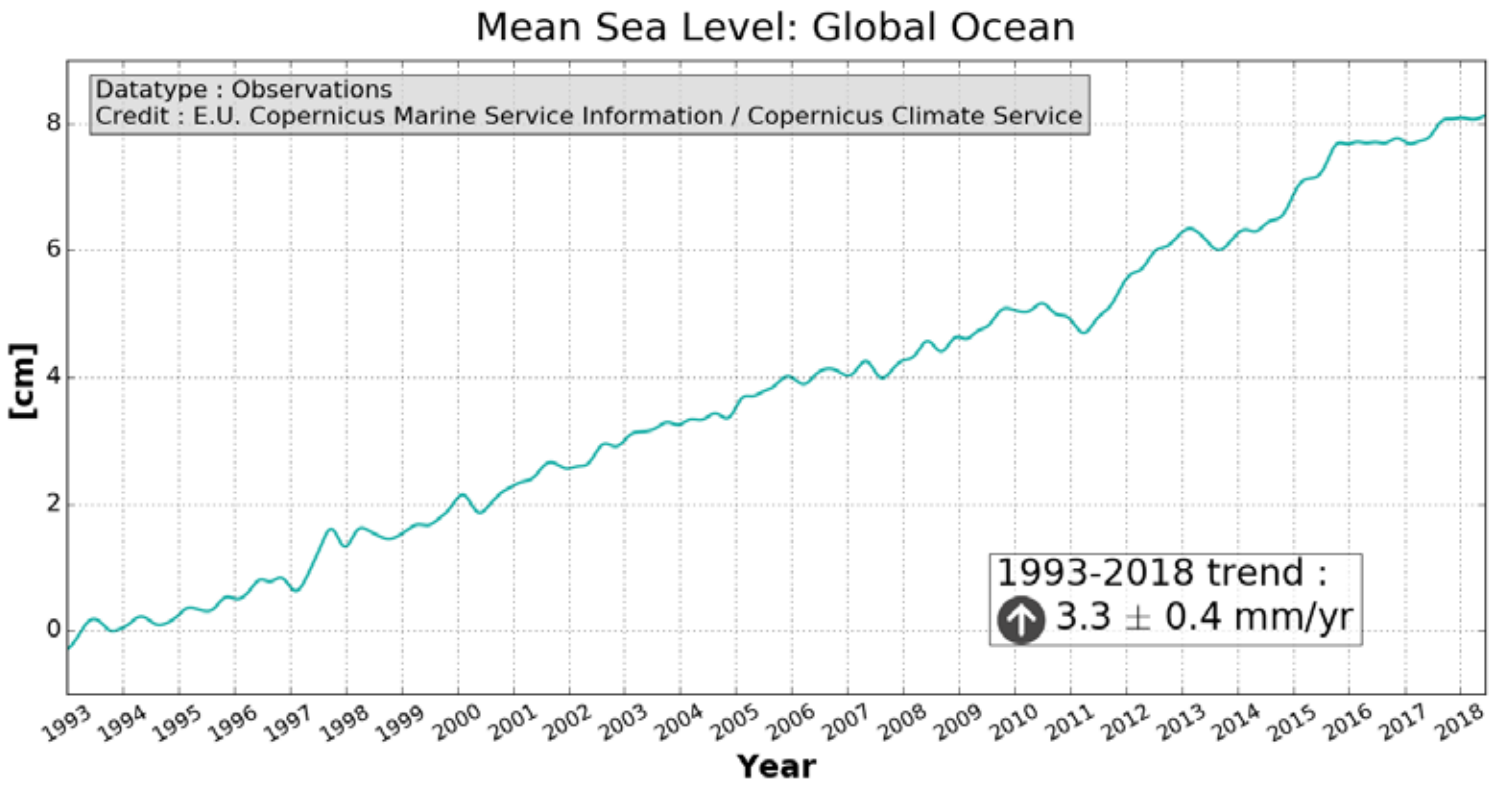


CPOM, Univ of Leeds.

Main contributions to sea-level budget 2004-2015



Glacier data from Zemp et al. (2019), other values from Cazenave et al. (2018), observed GMSLR: 3.5 mm per year



Copernicus Marine Service

Climate Change Service
climate.copernicus.eu

implemented by MERCATOR OCEAN INTERNATIONAL

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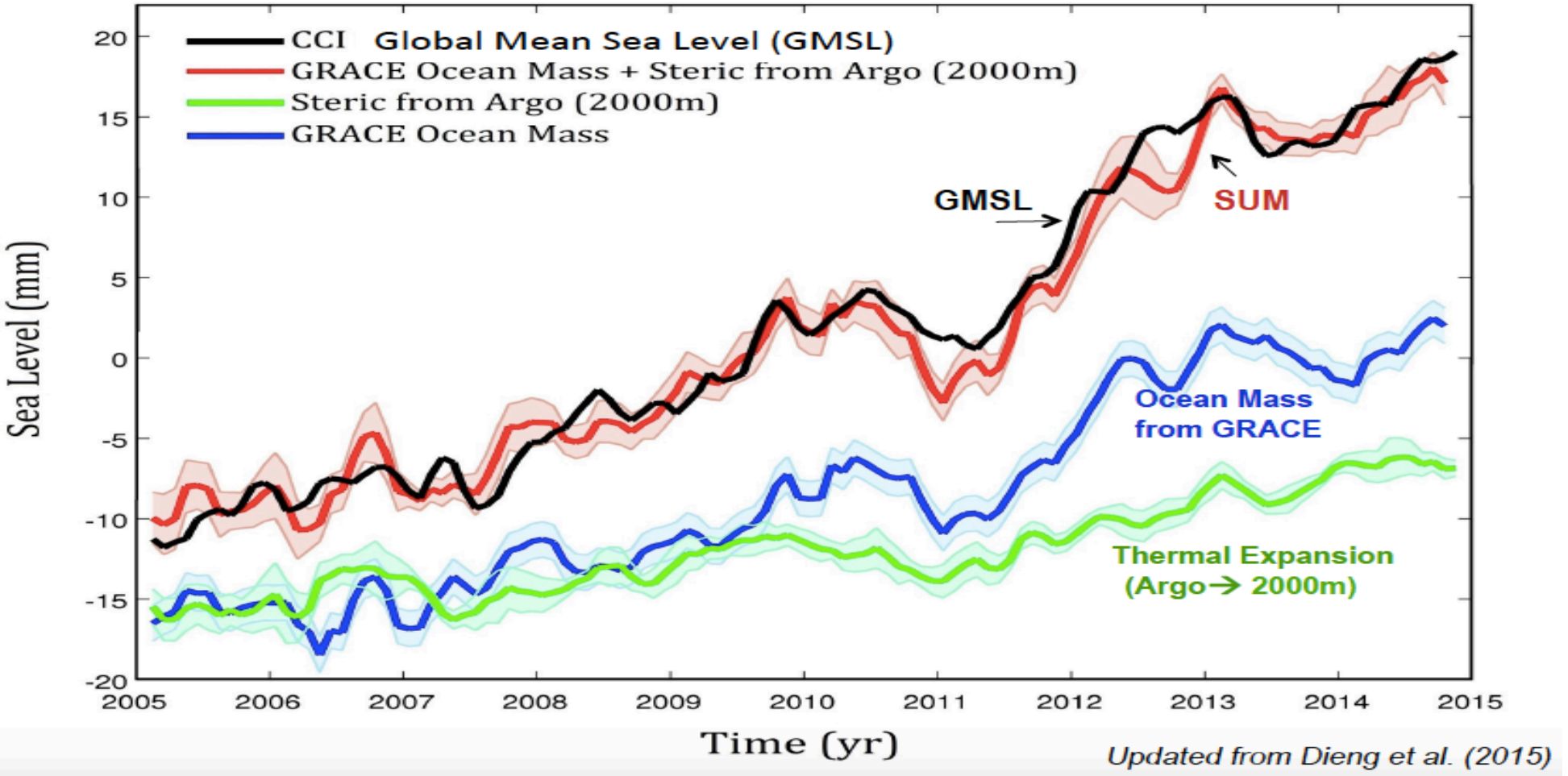
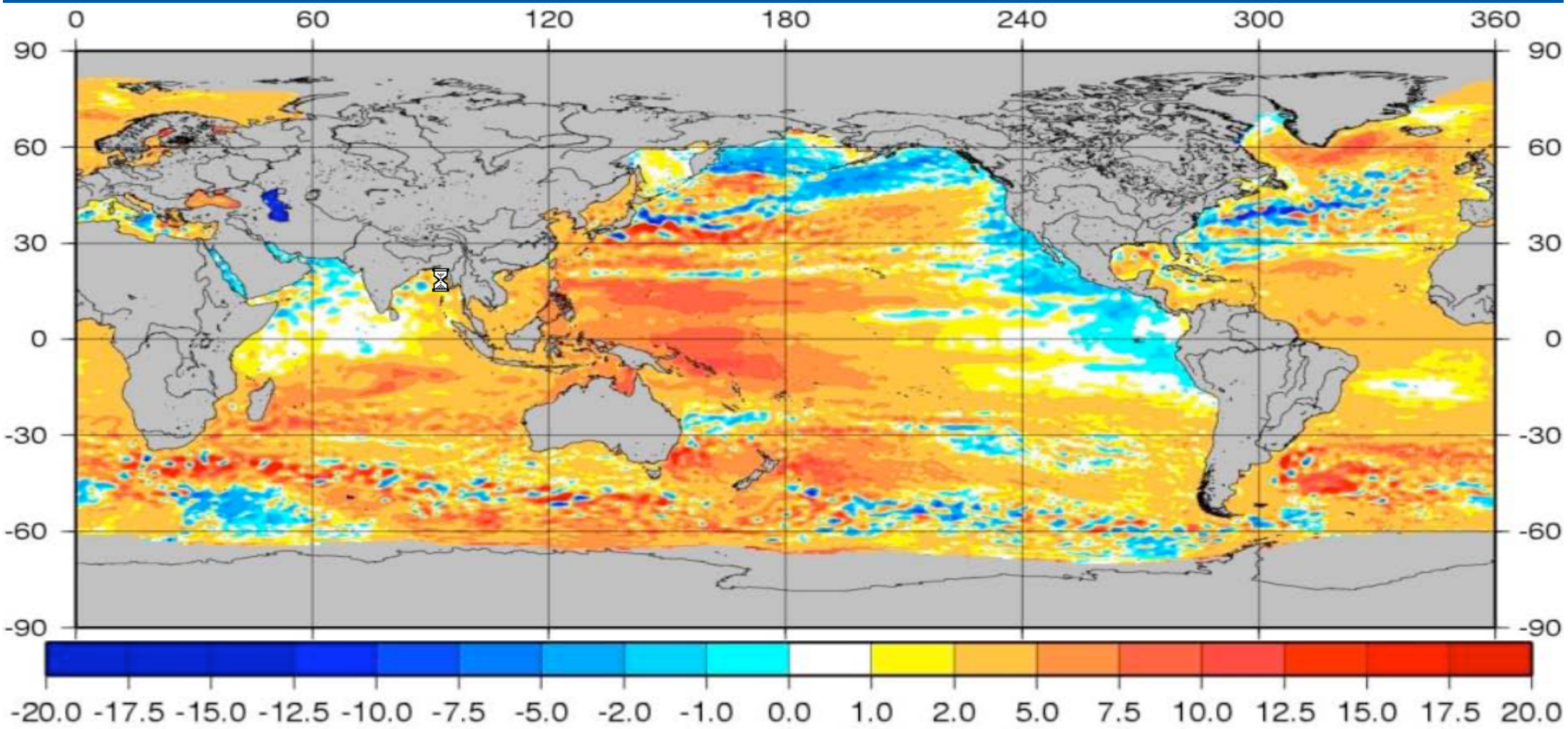


Updated from Dieng et al. (2015)

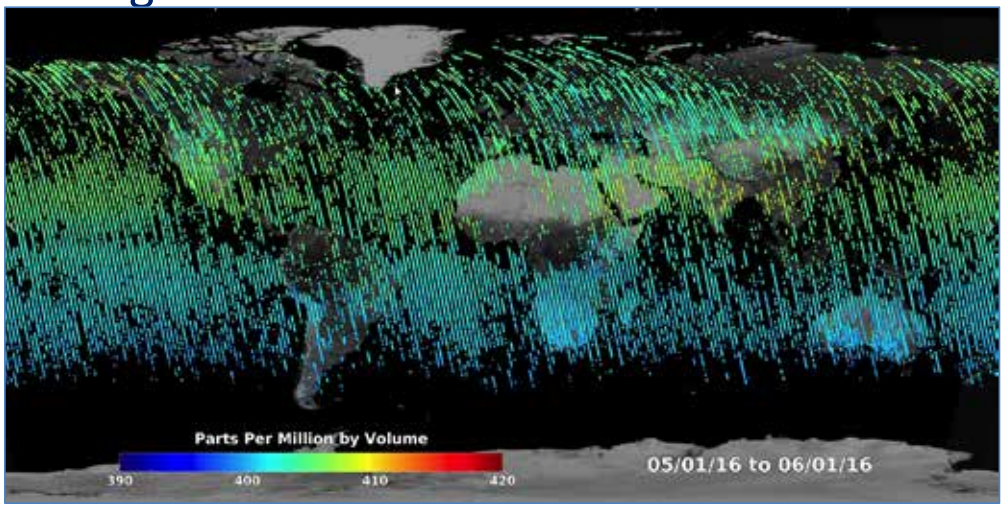
regional sea-level trends

mm p.a.

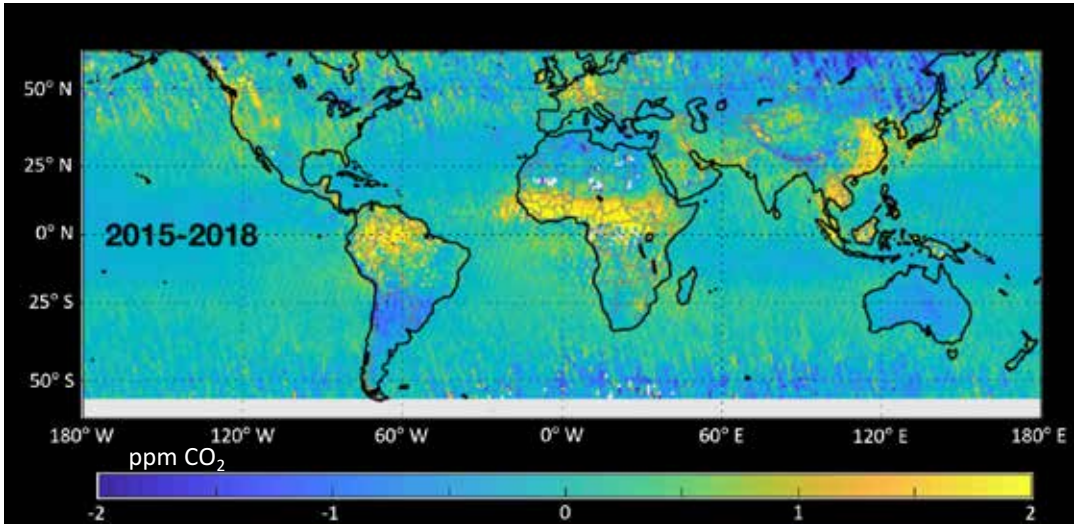


Space-based CO_2 and CH_4 Measurements Provide Increased Coverage and Resolution

Spatially-resolved estimates of the column-averaged CO_2 and CH_4 dry air mole fractions, XCO_2 and XCH_4, like those from NASA's Orbiting Carbon Observatory-2 (OCO-2) and Japan's Greenhouse gases Observing SATellite (GOSAT) are less precise and accurate than ground-based *in situ* data but provide high spatial and temporal resolution and greater coverage of the globe.

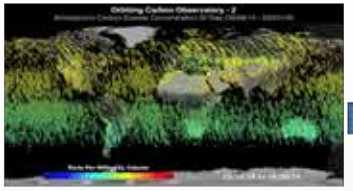


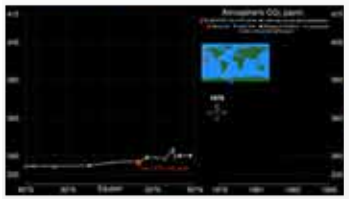
XCO_2 measurements collected by OCO-2 in May 2016.

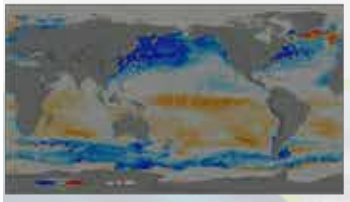


Persistent spatial anomalies in OCO-2 XCO_2 estimates for 2015 – 2018. Yellow regions have persistently high CO_2.

A System Approach for Atmospheric Inventories







Observations

- **Satellite Measurements of CO_2 and CH_4**
- **Ground and Airborne Measurements of CO_2 and CH_4**
- **Meteorology** Satellite & in-situ
- **Auxiliary Data** Satellite observations of CO, NO_2, clouds, aerosols ...

Prior Information

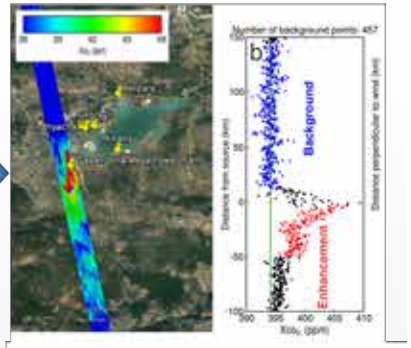
Fluxes, model parameters, emission reports, economic statistics.

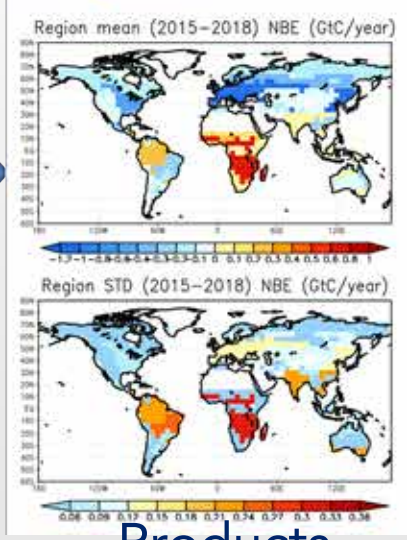
Integration & Attribution

- **Estimation system** Data assimilation and uncertainty estimation
- **Models** Transport, land & ocean carbon cycle, fossil fuel emissions.

Outputs

- **CO_2 and CH_4 emissions & removals from Hot-spots** with uncertainties
- **Country/region CO_2 and CH_4 emissions & removals** with uncertainties
- Other Carbon Cycle Products

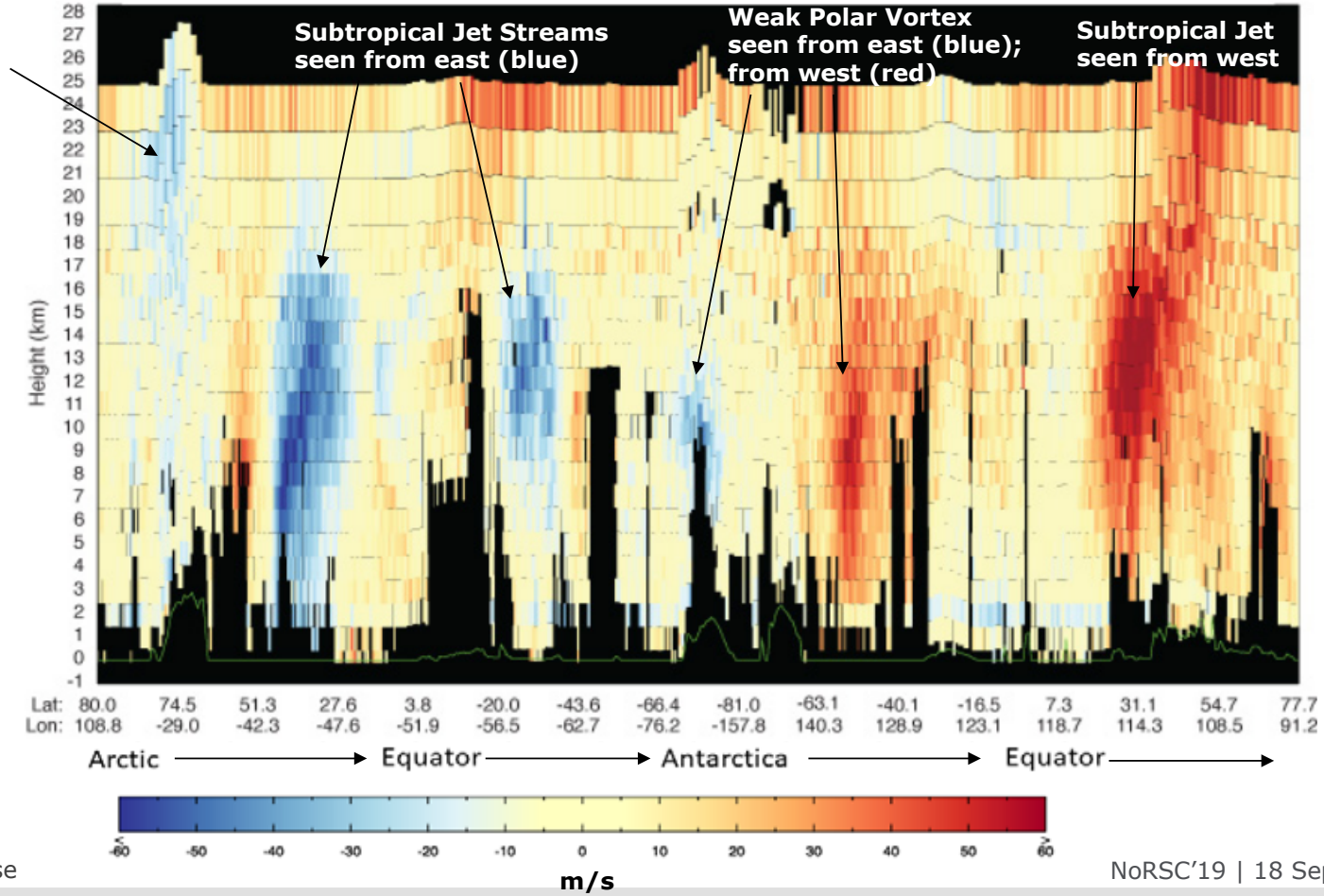




Measurements | Models | Products

Aeolus: Atmospheric Dynamics

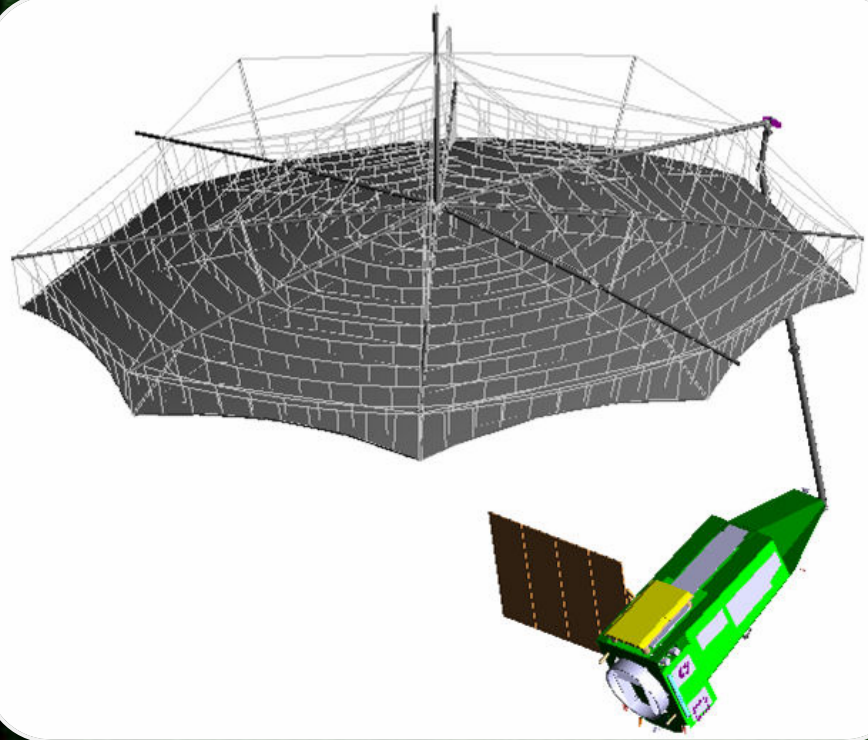
European Space Agency



27 February 2019

Biomass

Mission	Measure forest biomass and height (200 m. pixel)
Payload	P-Band radar
Orbit	SSO, alt: 666 km; LTAN: 06h00
Satellite	1250 Kg
Consortium	Prime: ADS-UK, Instrument: ADS-DE
Launch	2022



Sentinel Status

S-1

Radar

A	3 Apr. 2014
B	25 Apr. 2016
C	2022/23
D	> 2022/23

S-2

High Res. Optical

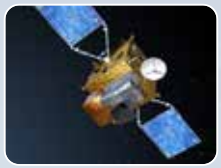
A	23 Jun. 2015
B	6 Mar. 2017
C	2022/23
D	> 2022/23

S-3

Medium Res. Optical & Altimetry

A	16 Feb. 2016
B	25 Apr. 2018
C	2023
D	> 2023

S-4



Atmospheric Chemistry (GEO)

A	2022
B	2027

S-5P

Atmospheric Chemistry (LEO)

A	13 Oct. 2017

S-5

Atmospheric Chemistry (LEO)

A	2021
B	2027
C	> 2027

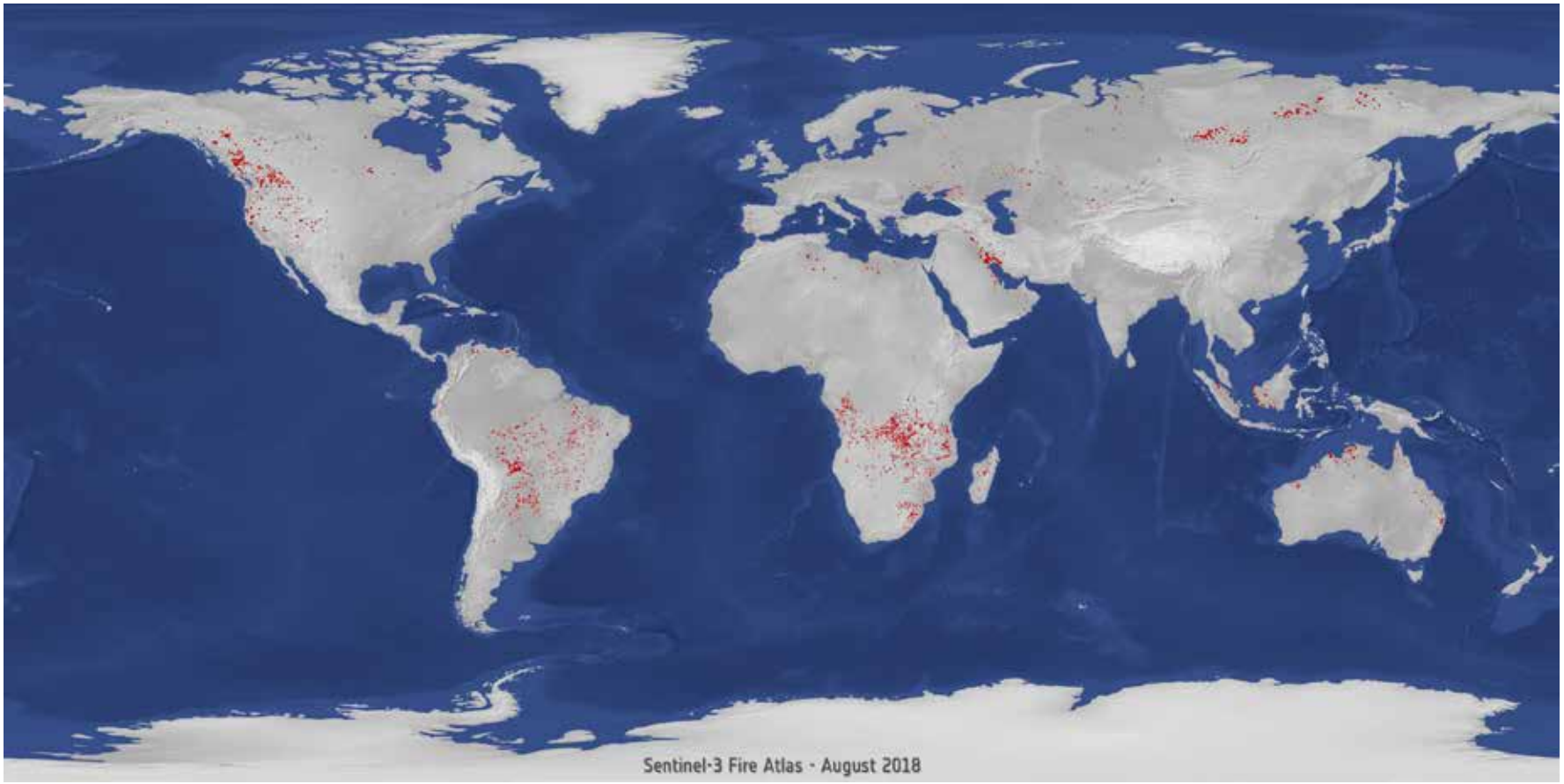
S-6

Altimetry

A	2020
B	2025

Global fires detected in August 2018 compared to August 2019

The Sentinel-3 World Fire Atlas recorded 79 000 wildfires in August 2019, compared to just over 16 000 fires during the same period in 2018.



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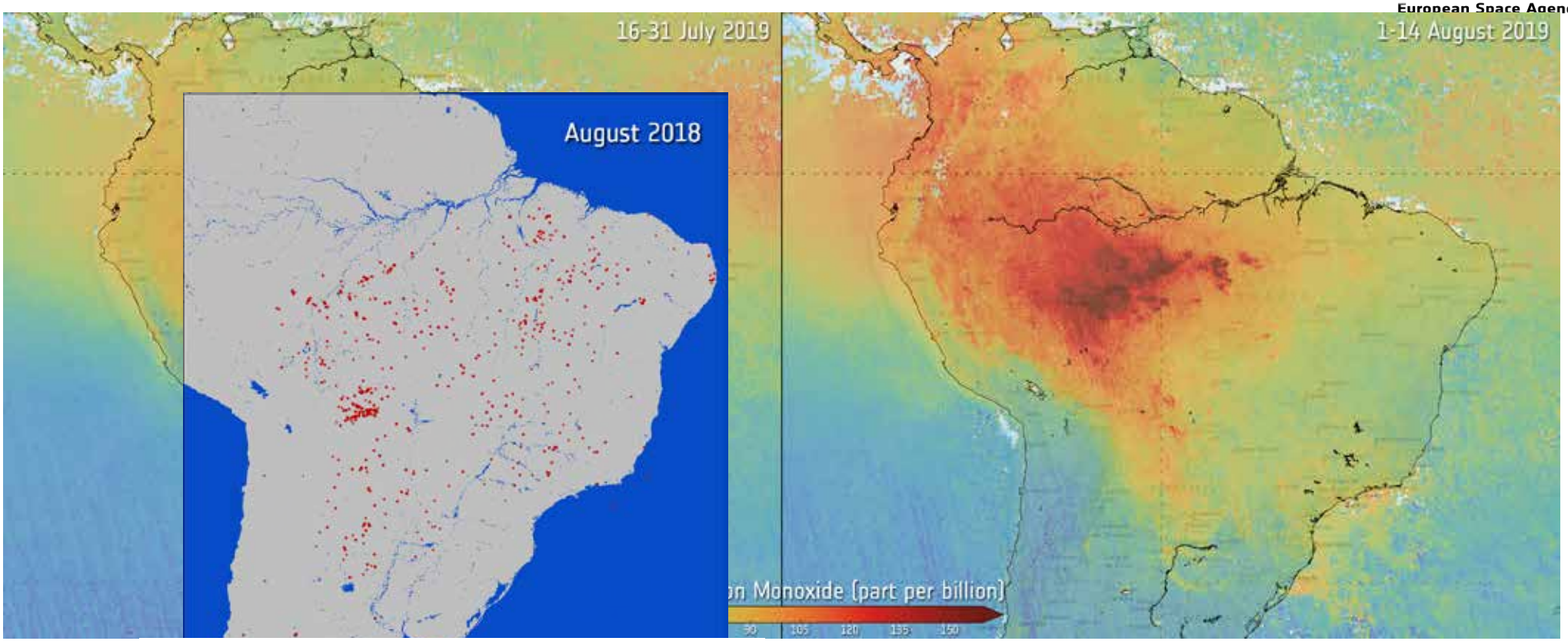
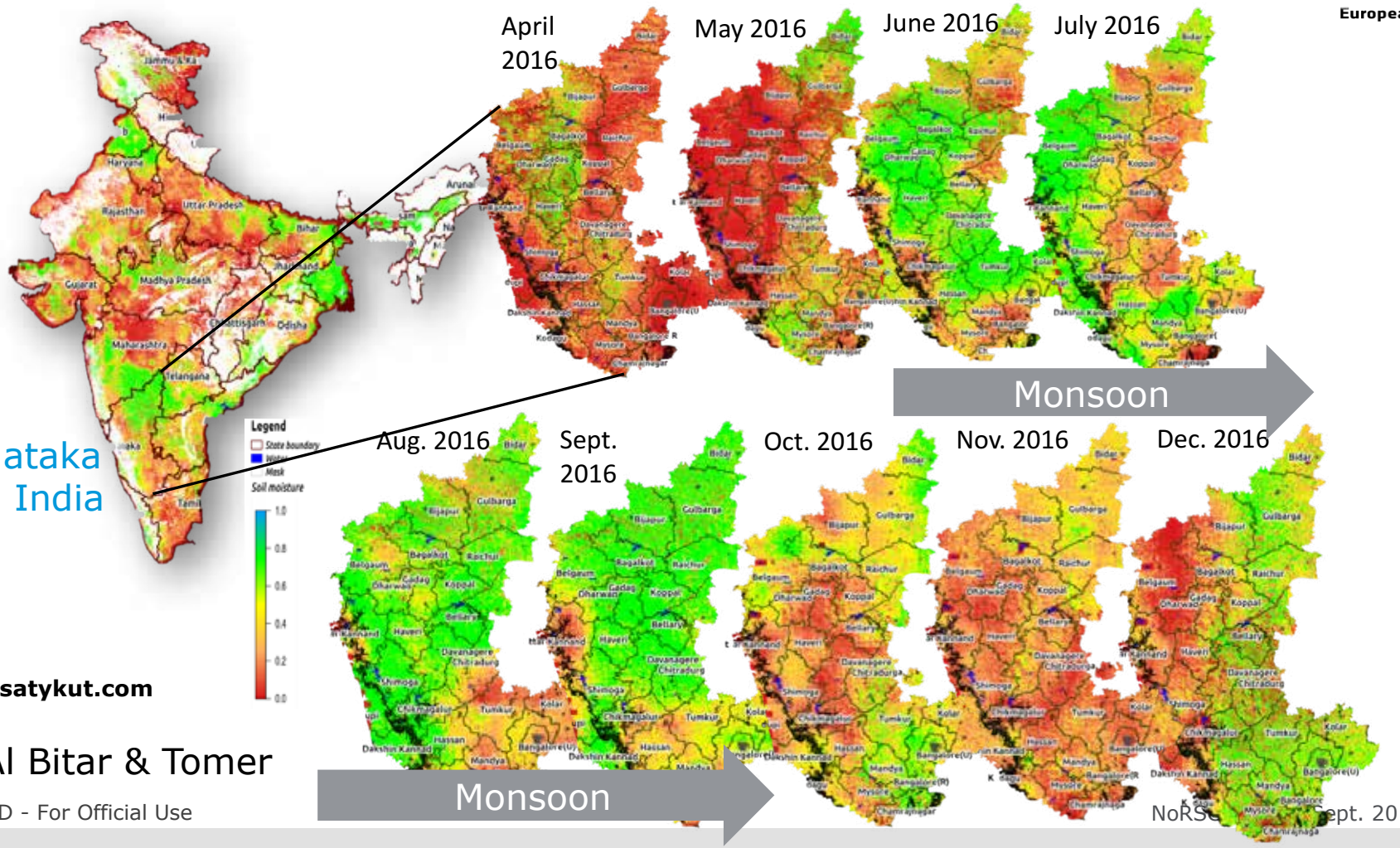
Sentinel-5p and Sentinel-3: Amazon Fires



See World Fire Atlas at:
https://s3worldfireatlas.esa.int/

See: Monitoring air pollution from fires

Sub-kilometric soil moisture (SMOS+S1 -500m)



Courtesy Al Bitar & Tomer

GCOS

Observation, Infrastructure & Information Systems

Weather, Climate, Water and related environmental Services and Applications

GCOS supports observations and production of climate the data records that underpin climate service delivery, e.g. for weather, hydrology, ocean cryosphere and biosphere.

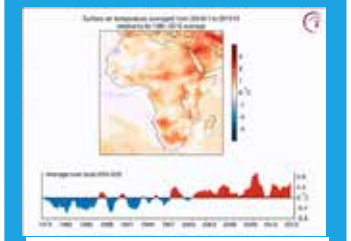
Sensing

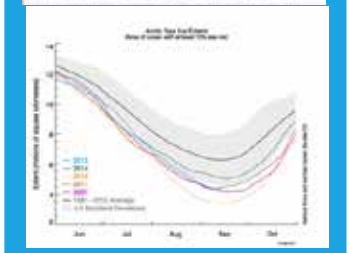
- Observation of the Earth System

Network and system operators: e.g. national meteorological services, satellite agencies

Data Records

- Preparation of Climate Data records
- Archiving,
- Reanalysis,
- Production of long datasets
- Climate projections





Data Managers, Modeler, Re-Analyses (ECMFW, NCEP, DWD, JMA, Research, data Providers, etc.)

Delivery of Services

- Delivery of targeted information for specific applications or to inform decisions

Service companies & agencies, (Copernicus, ESRI, Google Maps, national meteorological services)

Decision Making and Implementation

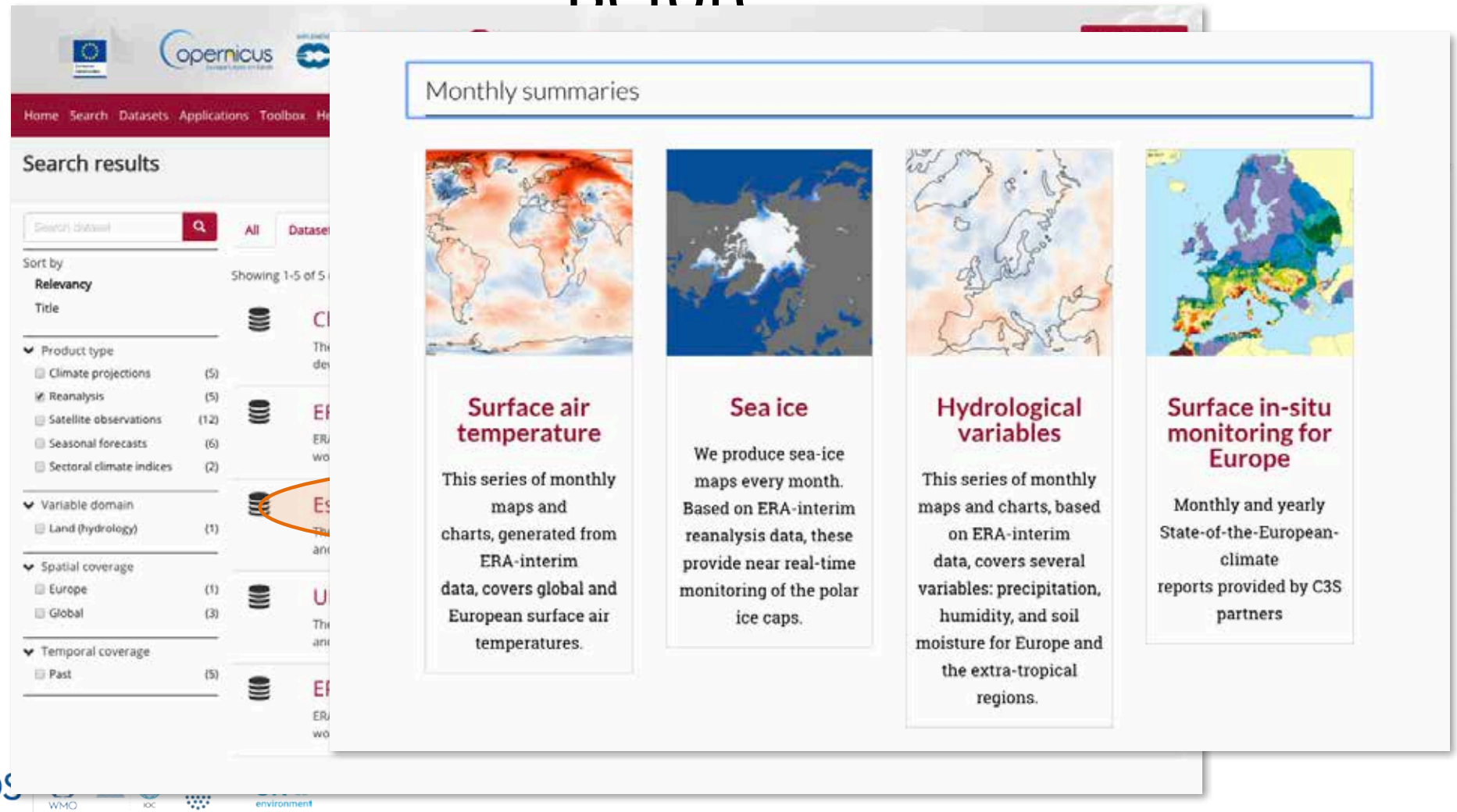
- Implement actions based on the information

National authorities, insurance companies, private sector

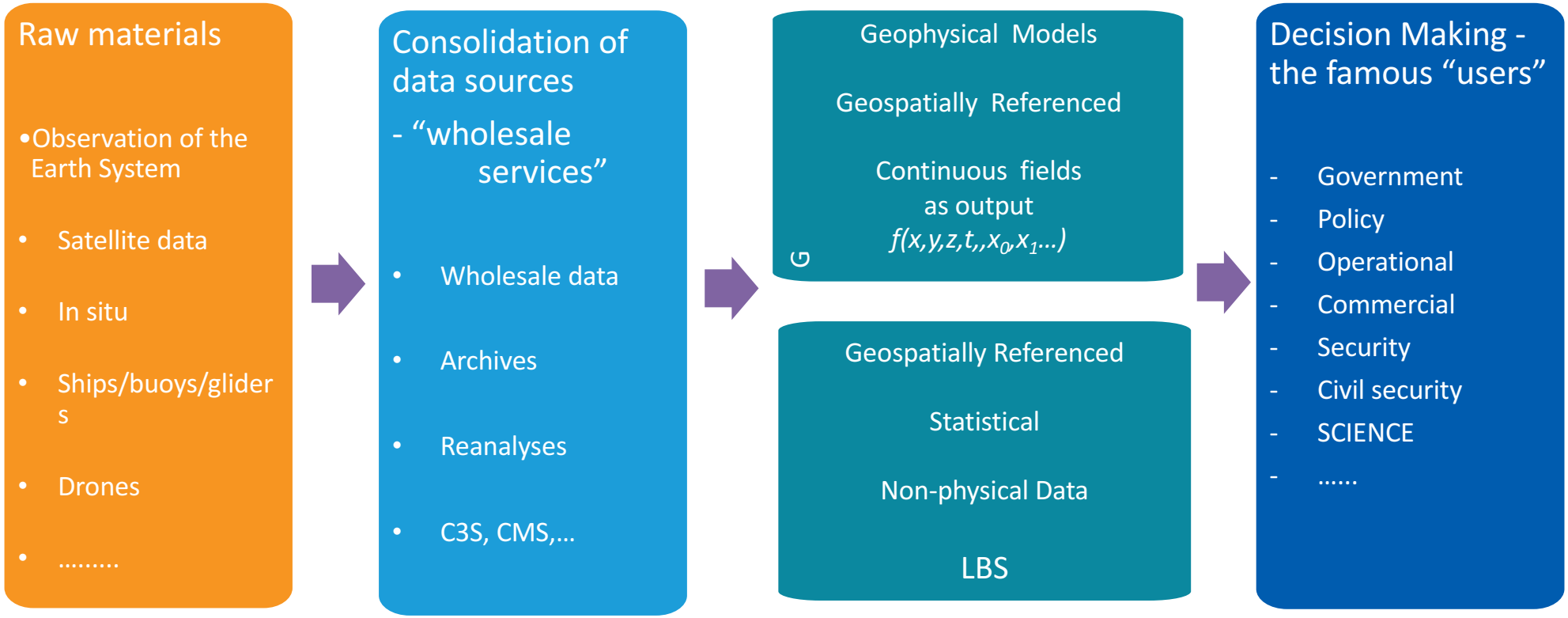
Feedback on user needs and gaps in observational and data systems

Reanalysis data and derived products

Before



Science inputs



GCOS WMO IOC UN environment

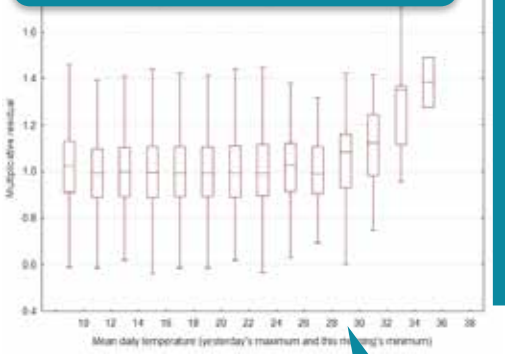
Evolving citizen data collection

Election Pope Benedict XVI

Election Pope Francis

Examples of remote sensing of responses to climate changes

Mortality increases with average temperature



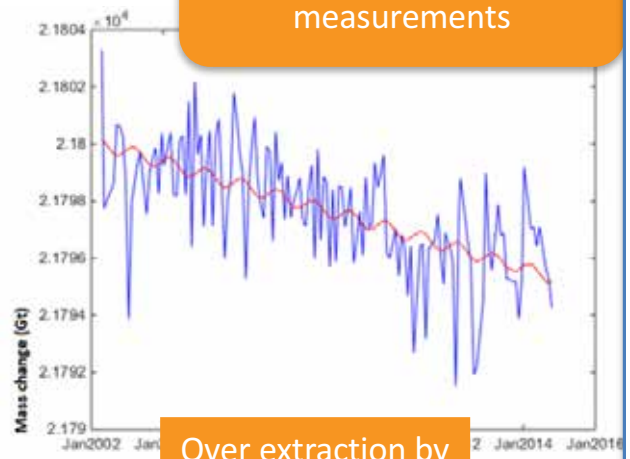
Expected Mortality leads to Actions to cool Cities

Overall impact of these actions can be monitored remotely

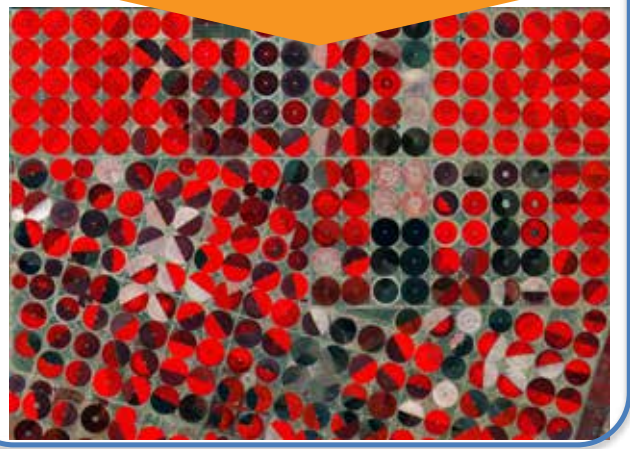
Adelaide. SOURCE: modified Copernicus Sentinel data (2017), processed by ESA, CC BY-SA 3.0 IGO

ECVs include:
Land Cover
Land Surface temperature
Ground water
Anthropogenic water use
Anthropogenic GHG

Ground water depletion in Saudi Arabia, GRACE measurements



Over extraction by agriculture



High resolution commercially available satellite data used for urban planning and climate adaptation – Jeddah, Saudi Arabia