Ice and Snow in the ESA Climate Change Initiative

Simon Pinnock, ESA Climate Office, Harwell, UK

With acknowledgement to my ESA colleagues:
Marcus Engdahl, Pascal Lecomte, and Stephen Plummer

And the CCI project teams led by:
Andrew Shepherd, Rene Forsberg, Frank Paul, and Stein Sandven

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ESA Climate Change Initiative

To realize the full potential of the long-term global Earth Observation archives that ESA together with its Member States have established over the last thirty years, as a significant and timely contribution to the Essential Climate Variable (ECV*) databases required by the United Nations Framework Convention on Climate Change (UNFCCC).

**** Requirements for ECVs are defined by GCOS***

cci.esa.int

CCI Objectives and Scope

CCI Objectives:

- **research**, **development**, **qualification** and **delivery to users** of pre-operational ECV products
- **definition**, **sizing** and **demonstration** of ECV processing systems
- **transfer** of ECV production to operational entities outside ESA

Driven by **climate user requirements** defined by GCOS, under authoritative advice from ESA's Climate Science Advisory Board, and strong coordination with the international Space Agencies response to GCOS via the Joint CEOS/CGMS Working Group on Climate (WGClimate).

ECVs Implemented in the CCI (2010-2017)

Atmosphere	Ocean	Terrestrial
Composition	**Surface**	
Aerosols Properties	Sea Surface Temperature	Land Cover
Carbon Dioxide & Methane	Sea Level	Fire Disturbance
Ozone	Sea Ice	Soil Moisture
Long-Lived Greenhouse Gases	Ocean Colour	Glacier and Ice Caps
Precursors (for Aerosols and Ozone)	Sea State	Ice Sheets
Upper Air	Current	Snow Cover
Cloud Properties	Sea Surface Salinity	Albedo
Temperature	Carbon Dioxide Partial Pressure	Leaf Area Index (LAI)
Water Vapour	Phytoplankton	FAPAR
Wind Speed and Direction	Ocean Acidity	Lakes
Earth Radiation Budget	**Sub Surface**	Above Ground Biomass
Surface	Carbon	Permafrost
Surface Air Pressure	Current	Ground Water
Surface Air Temperature	Nutrients	River Discharge
Surface Precipitation	Ocean Acidity	Soil Carbon
Surface Radiation Budget	Oxygen	
Water Vapour (Surface humidity)	Salinity	
Near-Surface Wind Speed, Dir	Temperature	
	Tracers	
	Global Ocean Heat Content	

Within CCI Scope	Started in CCI	

CCI Programme (2010-2017)

Horizontal Supporting Activities

- System Engineering WG
- Data Standards WG
- Colocation Meetings
- CMUG Integration Meetings

CCI ECV Projects

- Cloud
- Aerosol
- Greenhouse Gases
- Ozone
- SST
- Sea Level
- **Sea Ice**
- Ocean Colour
- **Glaciers**
- **Ice Sheets**
- Land Cover
- Fire
- Soil Moisture

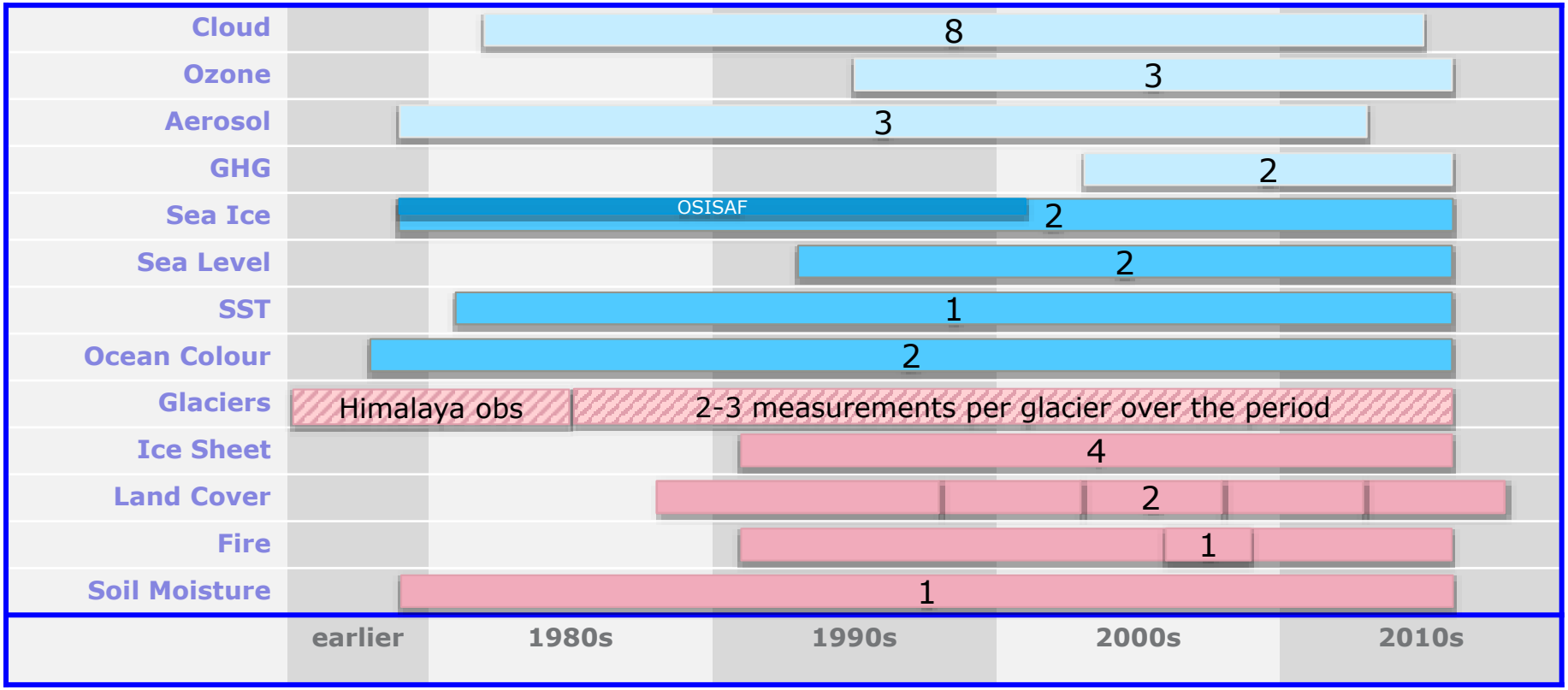
Cross-ECV & Exploitation

- Climate Modeller User Group
- Research Fellowships
- Cross-ECV Work Packages

Knowledge Exchange

- CCI Visualisation Tool
- CCI Open Data Portal (cci.esa.int)
- CCI Software Toolbox

CCI ECVs Time Coverage

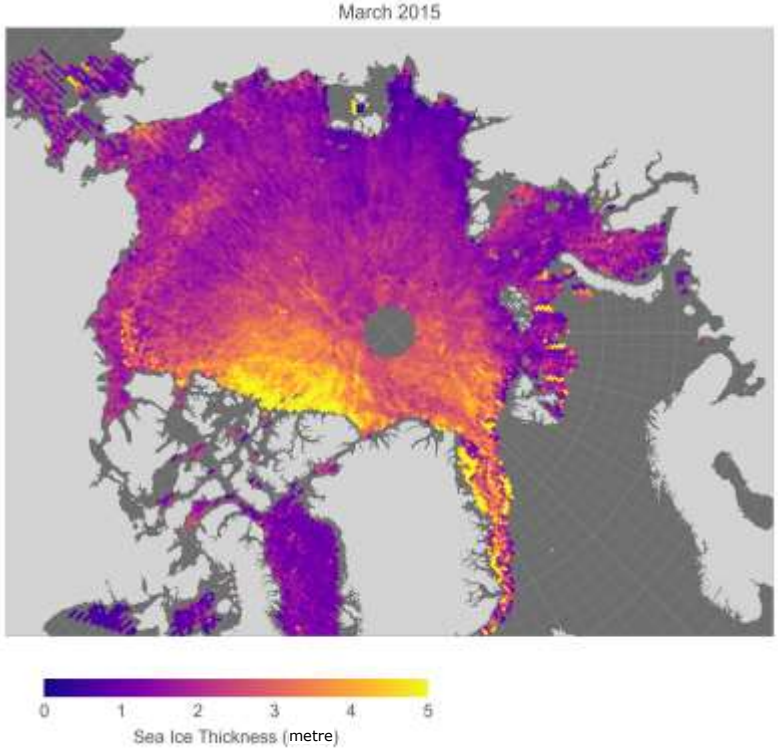


CCI Overall Achievements

- **Algorithm improvements** towards meeting GCOS ECV product, accuracy and stability requirements
- Delivery of **global multi-mission ECV time series** in a standard climate data format
- Development and provision of ECV product **uncertainty estimates** – in many cases this is completely innovative
- **Validation** of ECVs against the best available independent measurements
- **Climate user assessment** of ECV fitness-for-purpose
- Development of **sustainable data processing systems**
- Implementation of **open access** to all data products and reports
- Strong **international cooperation** with relevant agencies, scientific and user groups
- Progress on common **cross-ECV challenges** through programme-wide cooperation
- **Transfer of 8 CCI ECVs to operational production** in Copernicus C3S

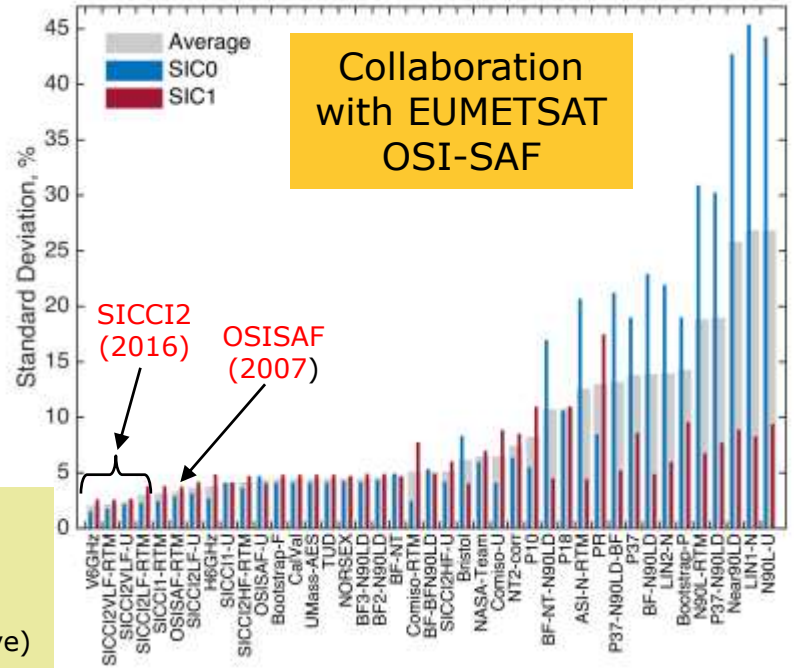
esa-cci.nersc.no

NERSC, CGI, MetNo, DMI, DTU,
FMI, AWI, U. Bremen,
U. Hamburg, Ifremer, MPI-M



Sea ice thickness in the Arctic from Envisat, CryoSat and Sentinel-3 Radar Altimeters

Collaboration with EUMETSAT OSI-SAF



Sea ice concentration algorithm accuracy (passive μ-wave)

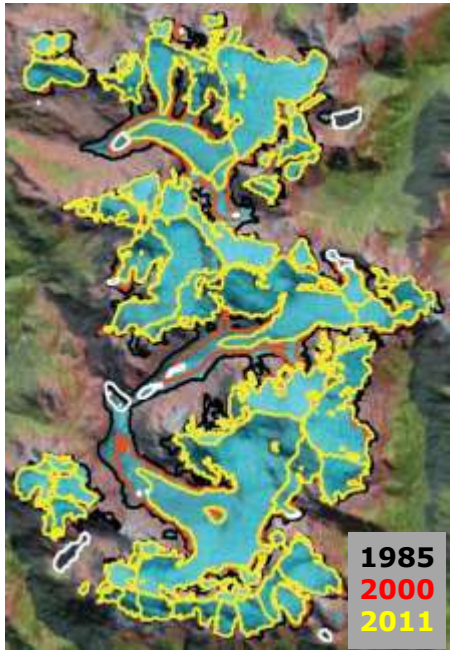
GCOS Requirements (GCOS-154)

Variable/ Parameter	Horizontal Resolution	Vertical Resolution	Temporal Resolution	Accuracy	Stability
SI Concentration	10-15km	N/A	Weekly	5% ice area fraction	5%
SI Extent/edge	1-5km	N/A	Weekly	5km	unspecified
SI Thickness	25km	N/A	Monthly	0.1m	unspecified
SI Drift	5km	N/A	Weekly	1km day^{-1}	unspecified

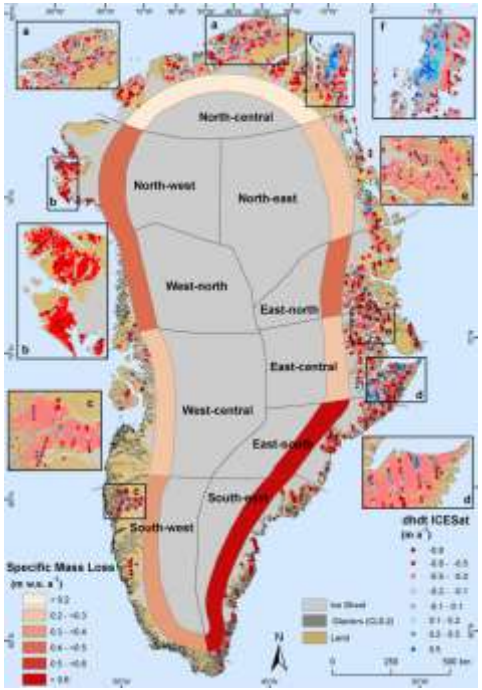
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GIUZ, ENVEO, GAMMA, GUIO, SEEL, U. Bristol, WGMS, GLIMS, ETH, NVE, KfG, ICIMOD



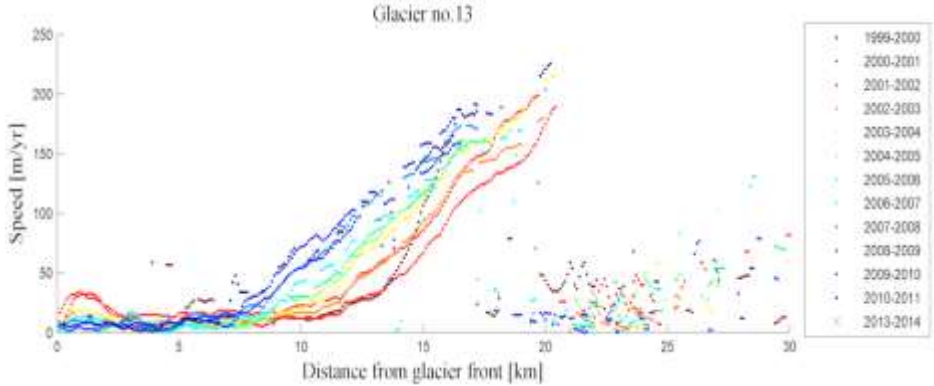
Area change assessment



Elevation change from laser altimetry for peripheral glaciers

GCOS Requirements (GCOS-154)

Variable/ Parameter	Horizontal Resolution	Vertical Resolution	Temporal Resolution	Accuracy	Stability
2D vector outlines, delineating glacier area	15 - 30 m	N/A	Annual (at the end of the ablation season)	better 5 %	15 m
Variable/ Parameter	**Horizontal Resolution**	**Vertical Resolution**	**Temporal Resolution**	**Accuracy**	**Stability**
Elevation data	30 - 100 m	1 m	Decadal	better 5 m	1 m



Time series of velocity profiles for 3 glaciers in the Karakoram from various sensors

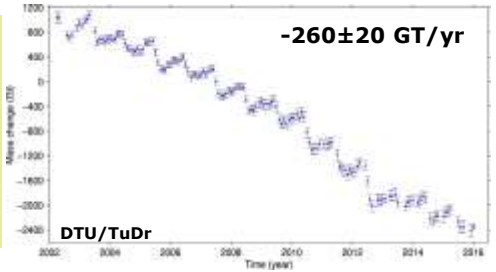
www.esa-icesheets-greenland-cci.org

DTU Space, S[&]T, U. Leeds, ENVEO, GEUS, NBI, NERSC, DMI

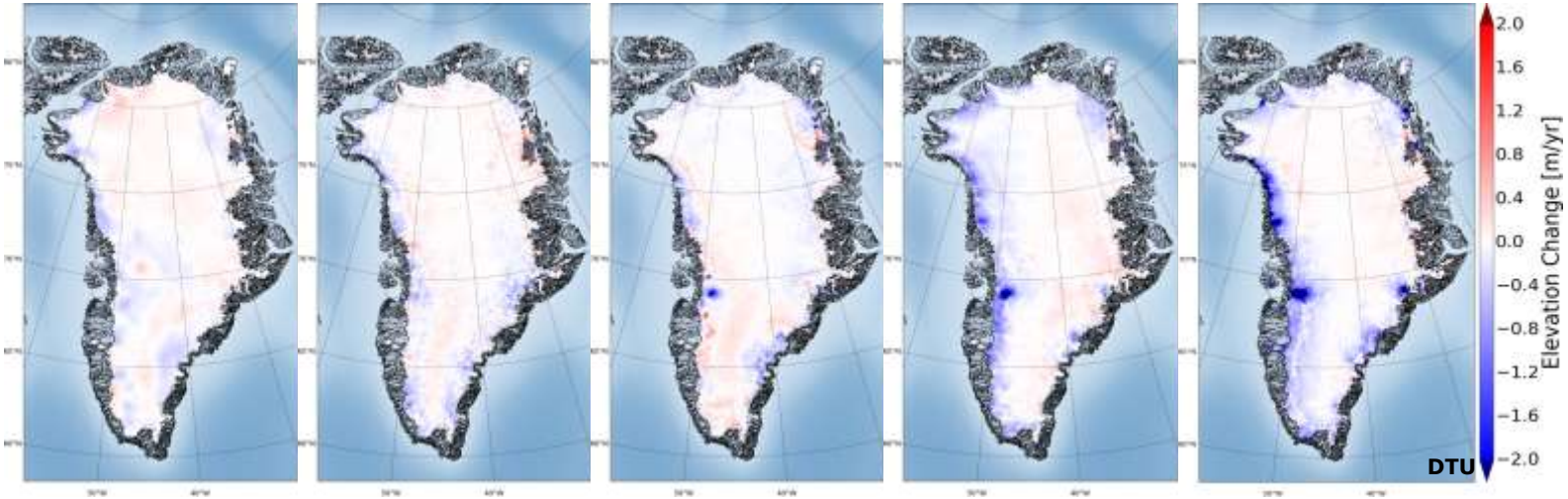
GCOS Requirements (GCOS-154)

Variable/ Parameter	Horizontal Resolution	Vertical Resolution	Temporal Resolution	Accuracy	Stability
Surface elevation change	100m	N/A	30 days	0.1m/yr	0.1m/yr
Ice velocity	1km	N/A	30 days	10m/yr	10m/yr
Mass change	50km	N/A	30 days	10km^3/yr	10km^3/yr

Overall mass change of the Greenland ice sheet



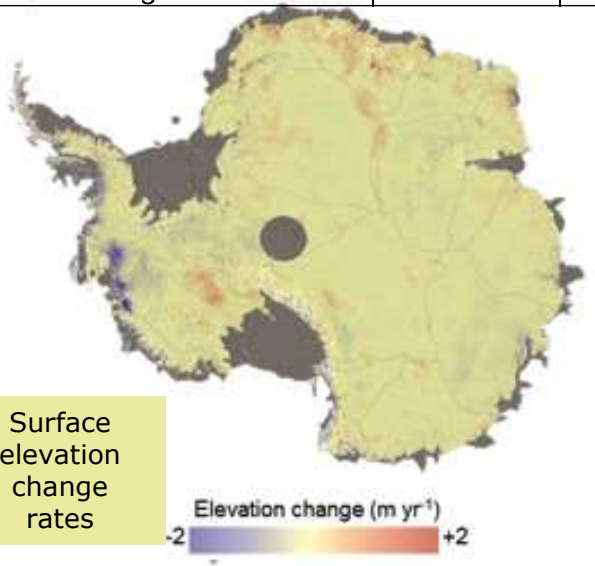
1992-1996 | 1997-2001 | 2002-2006 | 2007-2011 | 2011-2015



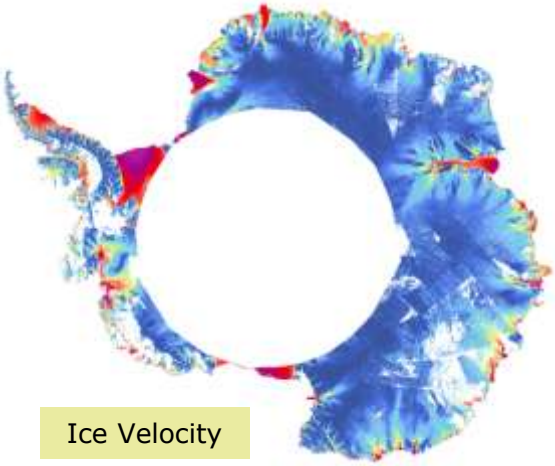
Seamless surface elevation change rates from ERS-1, ERS-2, Envisat and CryoSat (5 year running means)

GCOS Requirements (GCOS-154)

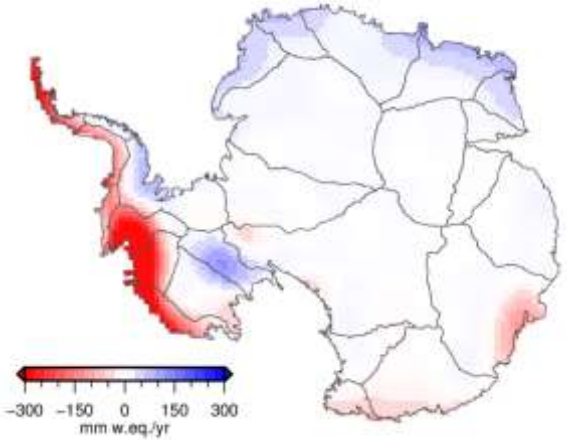
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Surface elevation change rates



Ice Velocity



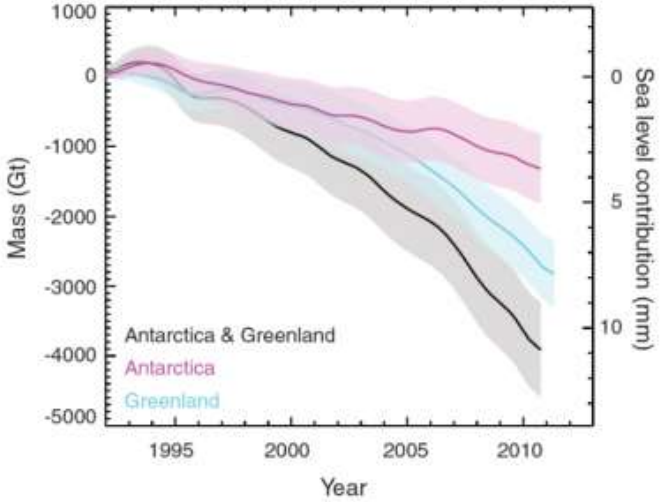
Gravimetric Mass Balance (TUD)

ESA-NASA Ice Sheet Mass Balance Intercomparison Exercise (IMBIE)

IMBIE is an international collaboration of polar scientists, providing improved estimates of the ice sheet contribution to sea level rise.

IMBIE 2012

Scientific Highlight: A reconciled estimate of ice sheet mass balance in Greenland and Antarctica.
Data Used: 10 satellite data sets, including ERS-1, ERS-2 and ENVISAT SAR and altimeter data;
Participants: 47 experts worldwide.



Cumulative mass change and sea level contributions from the Antarctic, Greenland, and combined Antarctic and Greenland ice sheets

IMBIE 2016

Objectives:

a) To conduct a community assessment of Greenland and Antarctica's ongoing contributions to global sea level rise.
b) To broaden participation across the scientific community
c) To improve understanding of any differences between estimates
d) To improve understanding of processes that are driving ice sheet imbalance.

Participants: 74 experts worldwide

www.imbie.org

CCI+

New subscriptions were made to ESA's CCI programme in Dec 2016 totalling 83M€.

Evolution of CCI over the period 2017-2024:

- CCI+ enables EO and climate research communities in Participating States to develop the ECV data products required by climate science (e.g. IPCC, CMIP, CoP-21) and for use in climate services.

Taking account of:

- new GCOS Status Report (2015) and new GCOS-IP (2016)
- new EO capabilities (e.g. Sentinels, Earth Explorers)
- new programmatic landscape (e.g. C3S, H2020, EUMETSAT CDOP-3, CMIP-6)

New ECVs in CCI+

Selection will be based on criteria endorsed by ESA Member States in 2009 and again in 2016:

- Response to GCOS requirements (revised in 2016)
- Availability, quality, uniqueness and importance of the satellite data
- Maturity of retrieval algorithms
- Ability to capitalise on European scientific expertise
- Prospects for transition to an external operational context

Taking into account:

- Overall level of Member States contributions
- Need for complementarity with other ECV activities in Europe (C3S, CDOP-3, H2020, etc.)

List of new ECVs will be selected in early 2017

- CSAB meeting in Jan 2017 to support ESA in formulating...
- CCI+ Implementation Plan to be presented to PB-EO in Feb 2017

Snow : a potential new ECV in CCI+

Snow

Snow has a major influence on the Earth's radiation balance, its high reflectivity driving the ice-albedo positive feedback. It is a sensitive and compelling indicator of climate warming, and an important source of water for agriculture.

Satellite Instruments

ATSR-2, AATSR, Sentinel-3 SLSTR, AVHRR, MODIS, VIIRS

Envisat ASAR, Sentinel-1 SAR

Sentinel-2, Landsat, etc. for validation

SMMR, SSM/I, AMSR, SMOS

Heritage

DUE GlobSnow and GlobSnow-2,

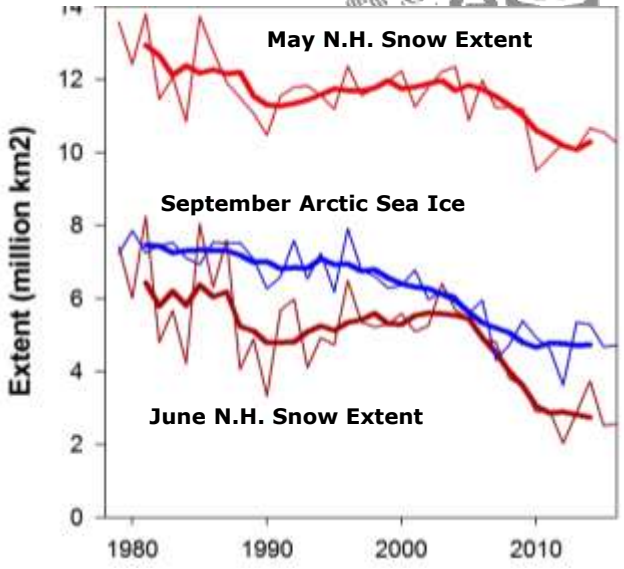
GSE PolarView, SnowPEx,

EC Cryoland, Sen3App,

H-SAF, CryoClim

The expected delta of CCI+

- Build on novel retrieval approaches developed in Europe to provide a snow cover CDR combining AVHRR, (A)ATSR, MODIS, VIIRS and Sentinel-3
- Work on improving quality of SWE CDRs (e.g. investigate possibility to retrieve snow density from SMOS)
- Investigate the potential for a CDR of wet snow derived from ASAR and Sentinel-1 over Europe
- Fully exploit Sentinel-2 for retrieval/validation, particularly in complex terrain.
- Strengthen international snow retrieval community built up by ESA's SnowPEx and NASA's iSWGR.



N. Hemisphere snow cover compared with arctic sea-ice decline (Derksen *et al.*/NASA/NOAA)

GCOS Requirements (GCOS-200)

ECV	Res.	Freq.	Uncertainty	Stability (10yr)
Snow Area	1km/100m	Daily	5%	4%
Snow Depth	1km/100m	Daily	10mm	10mm
Snow Water Eq.	1km	Daily	10mm	10mm

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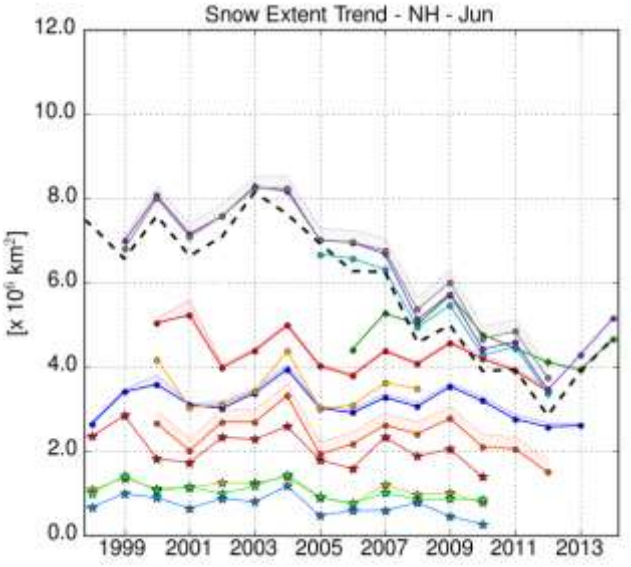
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SnowPEx (Nagler et al. 2017)

GCOS Requirements (GCOS-200)

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Snow Water Eq.	1km	Daily	10mm	10mm

Lakes: potl CCI+ ECV

Lakes

Lakes are reliable indicators of regional anthropogenic impacts and climate change. They also have a profound impact on surface-atmosphere exchanges.

Satellite Instruments

ERS, Envisat, Sentinel-3 altimeters

ERS, Envisat, Sentinel-1 SARs

MERIS, OLCI, (A)ATSR, MODIS, SLSTR

Sentinel-2, Landsat, ...

Heritage

SST_cci, Landcover_cci,

GlobTemperature, GlobDiversity, CoastColour

ESA's Rivers and Lakes project

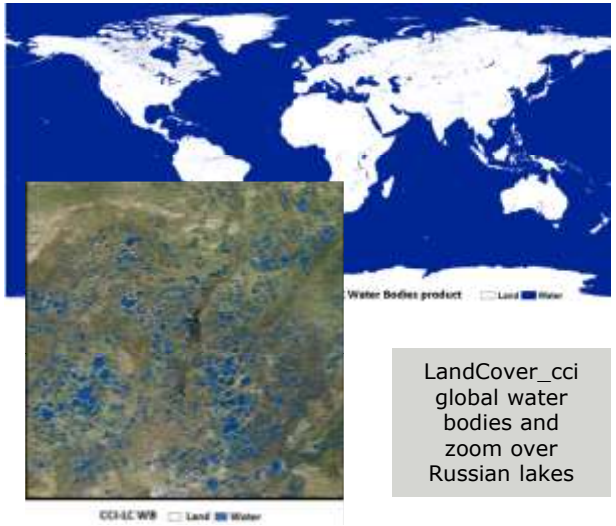
Global Lakes Sentinel Service (GLaSS)

ARC-Lake, GloboLakes, GLOWABO,

HYDROWEB, HYDROLARE

The expected delta of CCI+

- Development of a consistent and tailored set of long term geophysical variables characterising lake dynamics globally.
- Improve existing precursor products on LSWT, lake colour, lake area, lake level, lake ice, and adapt to new satellite infrastructure, such as the Sentinels and Cryosat-2.
- Coordinate US, Russia, Europe activities to provide products to the WMO Data Centre.
- Develop derived products on lake ice freeze-up and break-up dates.



LandCover_cci global water bodies and zoom over Russian lakes

ECV	Res.	Freq.	Uncertainty	Stab. (10yr)
Water level	100m	Daily	lg.3cm / sml.10cm	1cm
Water extent	20m	Daily	lg.5% / sml. 10%	5%
Water temp.	300m	Weekly	1K	0.1K
Ice thickness	100m	Monthly	1-2cm	-
Ice cover	300m	Daily	10%	1%
Water colour	300m	Weekly	30%	1%

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Permafrost : a potential new ECV in CCI+

Permafrost

A clear warming trend in N.H. permafrost borehole temperatures since 1980s. Thawing allows soil degradation/respiration leading to the release of CO_2 and CH_4 greenhouse gases, potentially amplifying global warming. But cannot be directly observed from space.

Satellite Instruments

MERIS, (A)ATSR, Sentinel-3 OLCI, SLSTR
AVHRR, MODIS, VIIRS
ERS/Envisat/Sentinel-1 SAR
Landsat, Sentinel-2
Passive microwave

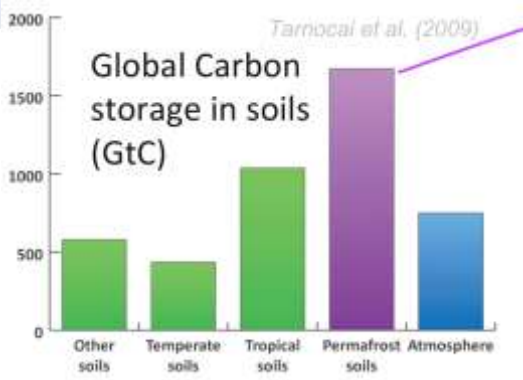
Heritage

DUE PERMAFROST & GlobPermafrost
Global Terrestrial Network for Permafrost
International Permafrost Association
NSIDC

The expected delta of CCI+

- Develop products for land surface hydrology, vegetation, freeze/thaw state of the active layer, and snow cover and use in combination with meteorological data to determine permafrost conditions.
- Tailor other ECV products for permafrost research: Snow, LST, Lakes, Land Cover, Soil Moisture, Fire.
- Validation of model results driven by above parameters against IPA/GTN-P observations.
- Inter-comparison of results with multiple model and NSIDC CALM outputs.





GCOS Requirements (GCOS-200)

ECV	Res.	Freq.	Uncertainty	Stability (10yr)
No satellite product requirements specified yet.				

Snow and Ice in ESA's Climate Change Initiative

Since 2010 CCI has been working on cryosphere ECVs:

- **Sea Ice**
- **Glaciers**
- **Ice Sheets (Greenland and Antarctica)**

CCI+ (2018-2024) will continue R&D on Sea Ice, Glaciers and Ice Sheets ECVs.
ESA is planning to initiate work on new ECVs, potentially including:

- **Snow**
- **Lakes (including lake ice)**
- **Permafrost**

Calls for projects on new ECVs are planned to be issued in Sept 2017.

All ECV data products are freely available from the CCI Open Data Portal (**cci.esa.int**)