NOAA SAT meeting
4 April 2022

# Towards consistent exploitation of Earth system observations in coupled assimilation systems

Patricia de Rosnay, Phil Browne, Eric de Boisséson, David Fairbairn, Kenta Ochi, Dinand Schepers, Pete Weston, Hao Zuo, Yoichi Hirahara, Mohamed Dahoui, Stephen English, Tony McNally,
and many others

ECMWF EUROPEAN CENTRE FOR MEDIUM-RANGE WEATHER FORECASTS

# Earth system assimilation: ECMWF strategy


**Strategy 2021-2030**

- Initialisation of global forecasts using a convection-permitting model

- Enhance consistency of assimilation approaches and optimal level of coupling between the various components of the Earth system

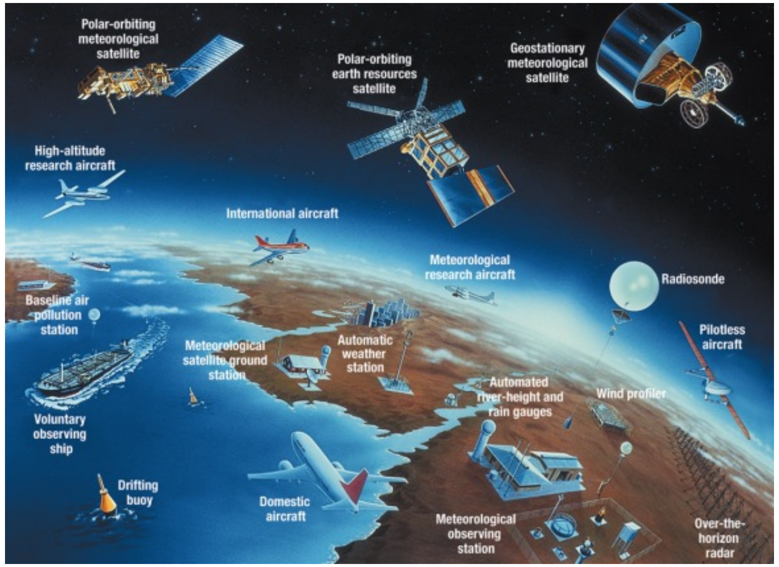
- Improve assimilation of satellite data sensitive to snow, sea and sea ice surfaces → “all surface” approach

- Machine learning integrated in model and data assimilation to support performance enhancement

- Efficient use of current and next generation of satellite data

https://www.ecmwf.int/en/about/what-we-do/strategy

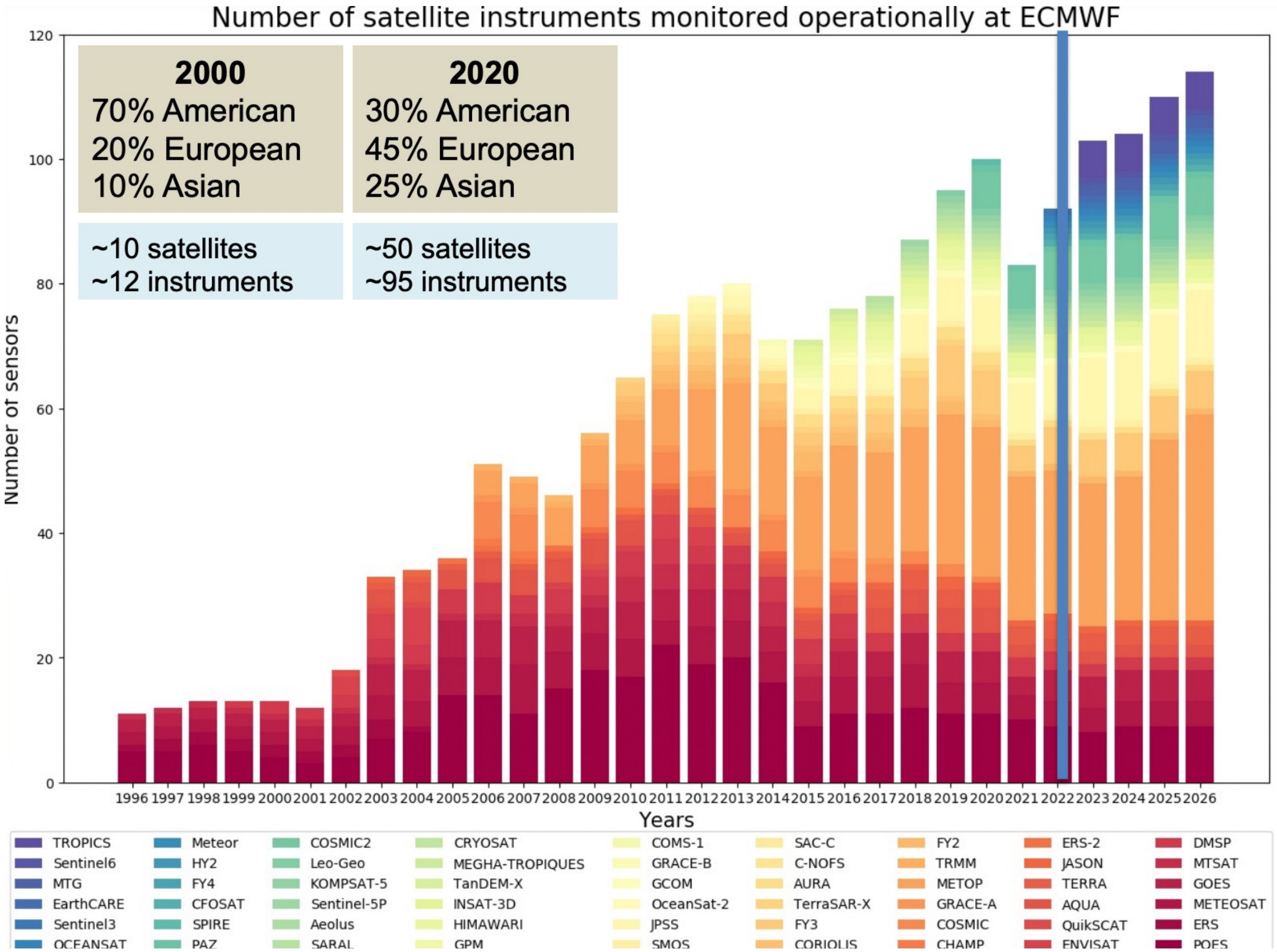
# Earth system assimilation of current and future observations




(Image copyright WMO)

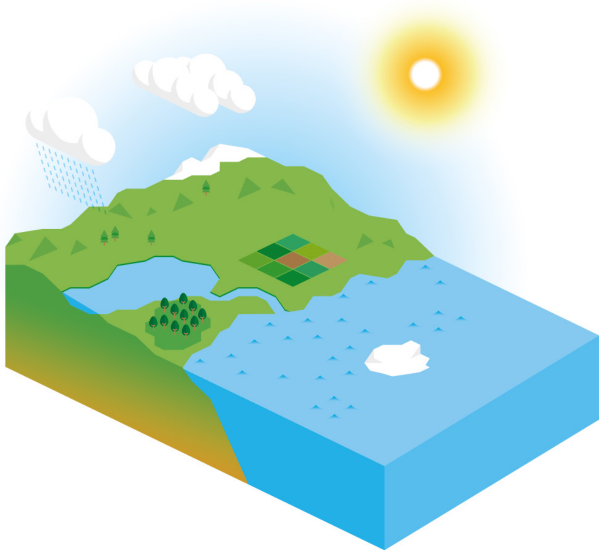
Upcoming satellite data:

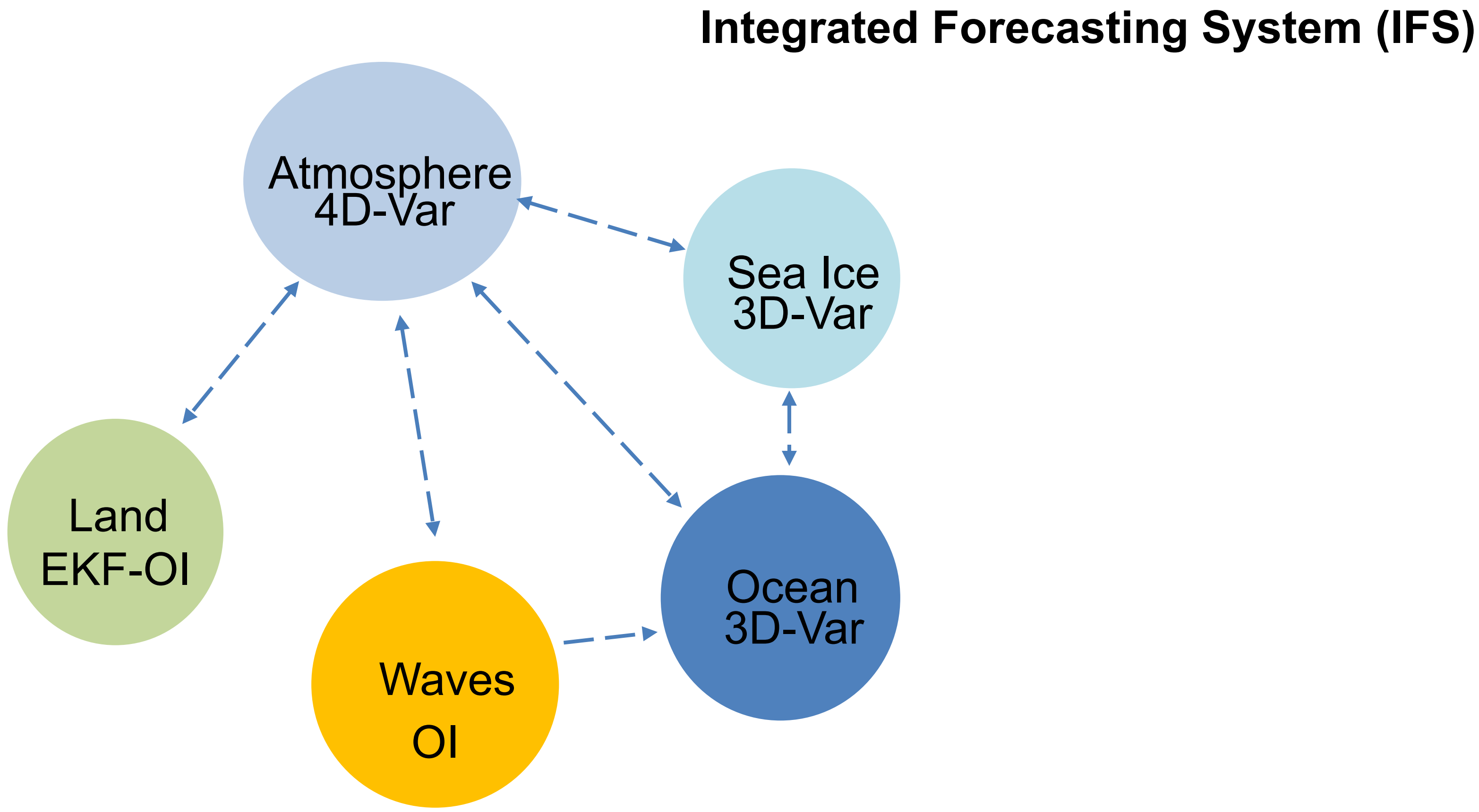
- Commercial providers
- Diversity of space agencies
- MTG, EPS-SG, Sentinels




(Thanks to Mohamed Dahoui and Steve English)

# Earth system approach





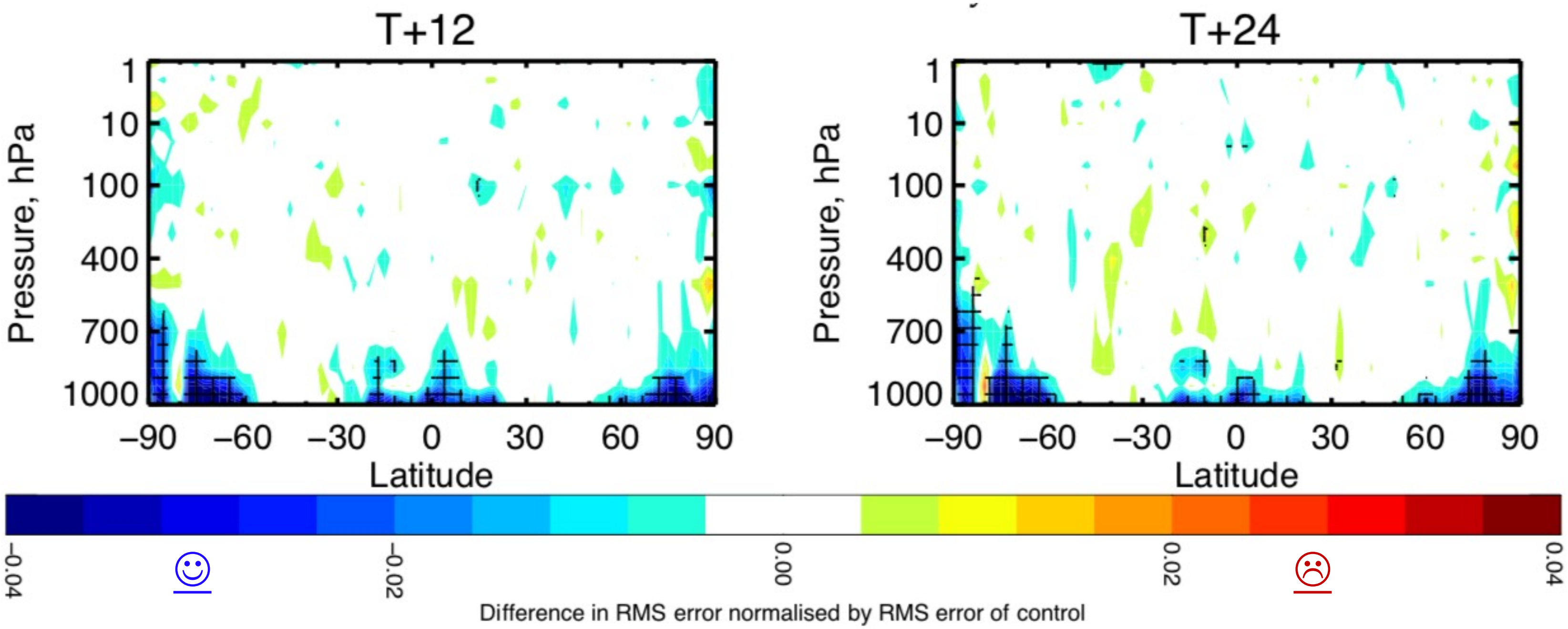

- Coupled assimilation developments for NWP and reanalyses
- Importance of interface observations (e.g. SST, sea ice, snow, soil moisture)

# Ocean-atmosphere weakly coupled assimilation through sea ice and SST

June 2017-May 2018

Impact on Temperature Forecasts

Normalized RMSE difference
(coupled DA – uncoupled DA)

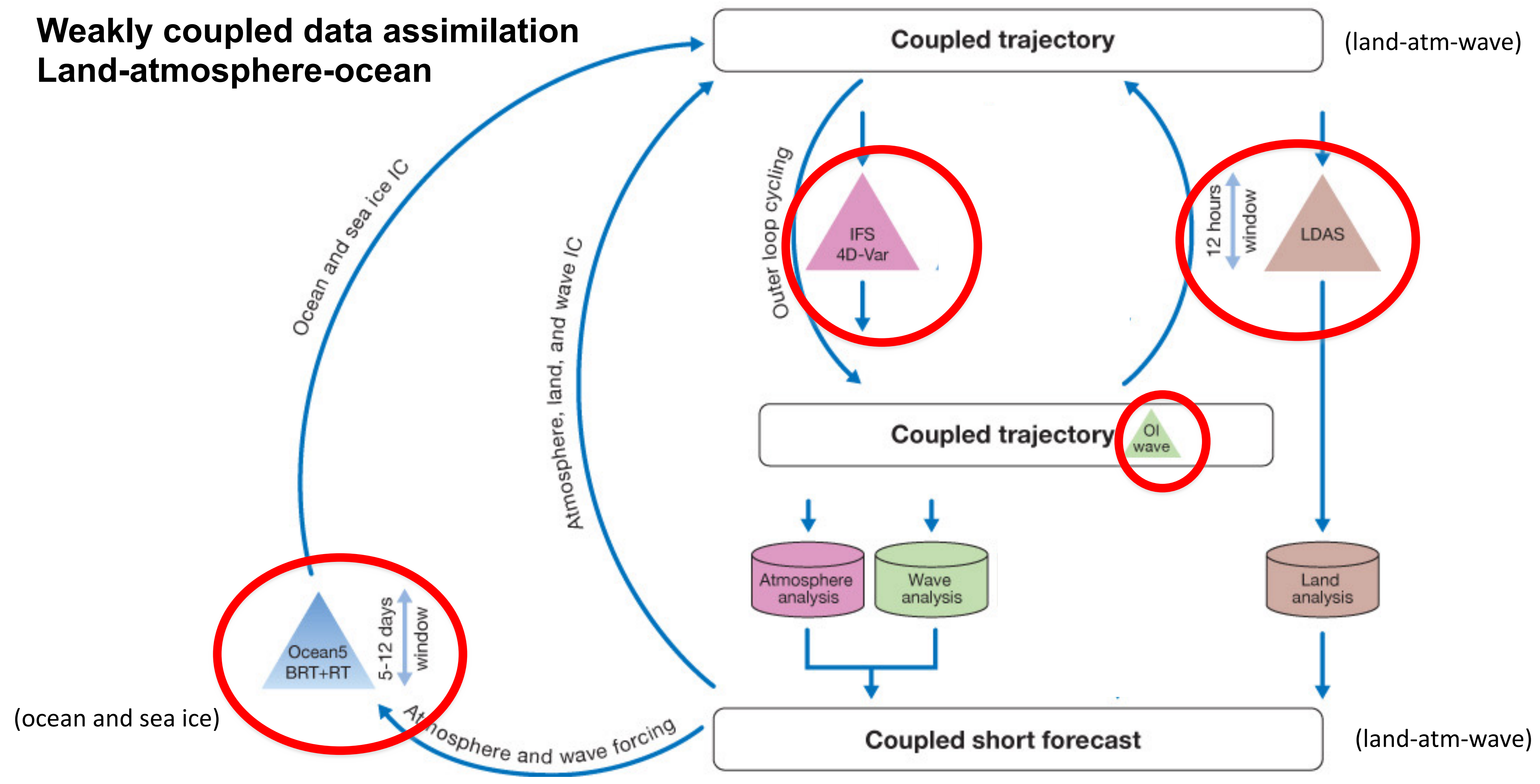



**(b)** dRMSE of temperature (K)
(June 2017 to May 2018)

**Browne et al., Remote Sensing, 2019**

# Coupled Assimilation for operational NWP at ECMWF

**Weakly coupled data assimilation**
**Land-atmosphere-ocean**



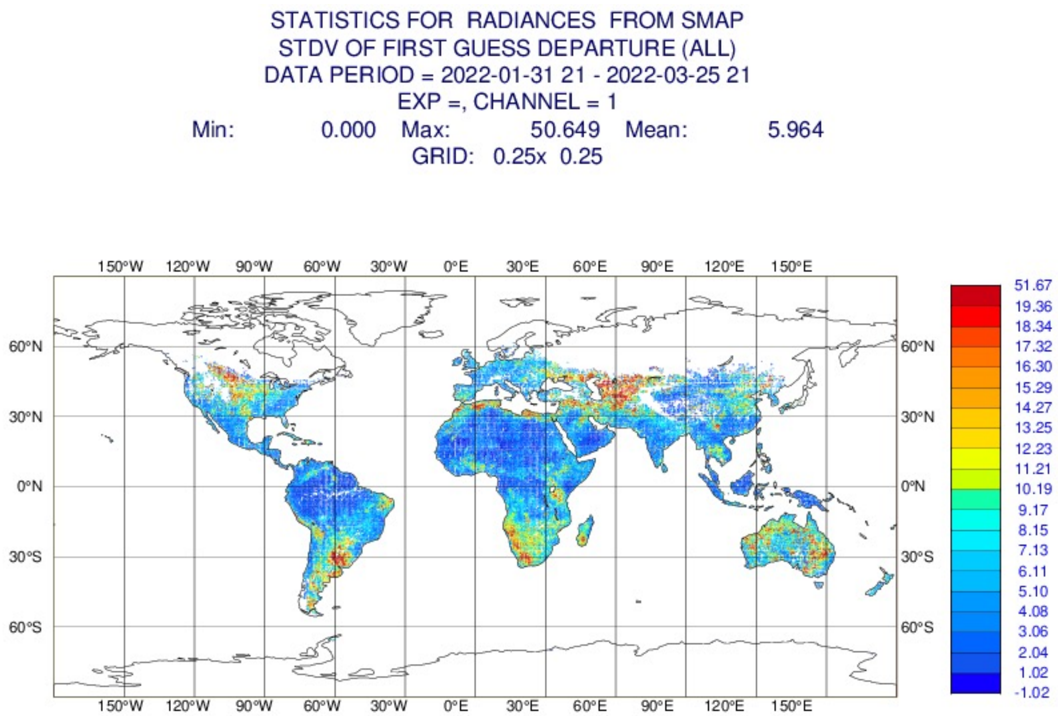
# Earth system observations acquisition and monitoring

Need of timely, sustainable and reliable access to observations across the Earth system components

- **Observations sustainability** for land, cryosphere and for the ocean → level of support from governing bodies to ensure in situ data provision, relevance of WMO data policy evolutions; works of JET-EOSDE, GCW, SG-CRYO, GOOS, etc…

- **Observations acquisition:**
  - Operational acquisition streams needed, e.g. Interface Control Document for Sea Level and SST Observations acquisition
- **Observations monitoring:**
  - Ocean operational monitoring (since 2017)
  - Land operational monitoring (since 2013), SYNOP monthly ‘blocklist’ & auto-alert (since Sept 2020)

SMAP L1B brightness temperature monitoring StDev (O-B) in K; Feb-March 2022




https://www.ecmwf.int/en/forecasts/quality-our-forecasts/monitoring-observing-system

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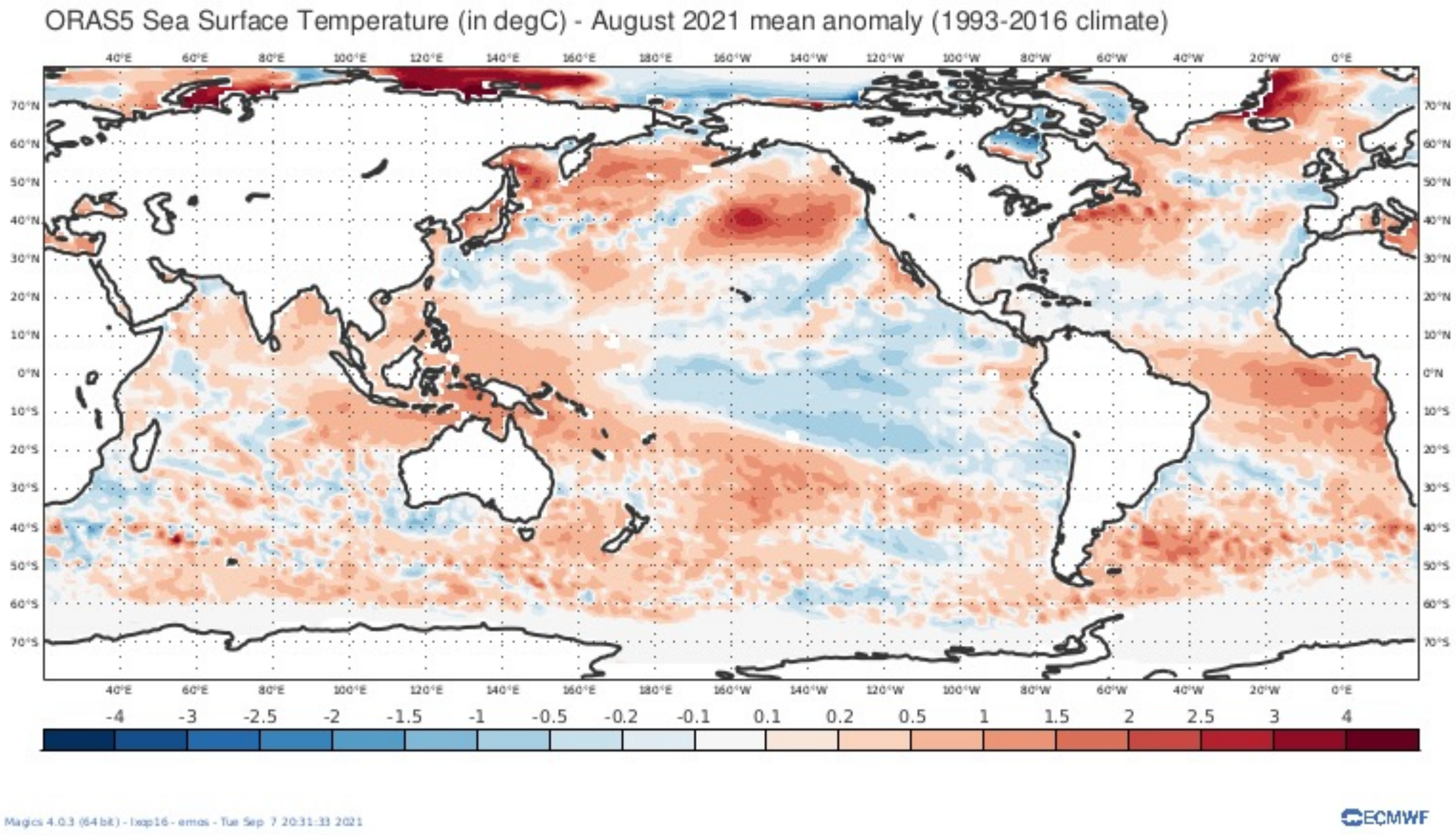
# Ocean system model space monitoring

Based on OCEAN5
**Zuo et al., Ocean Sci 2019**

- ORAS5 (reanalysis) monitoring: model space monitoring as part of the OCEAN5 system
- Monthly statistics and anomalies
- Publicly available on: https://www.ecmwf.int/en/forecasts/charts/oras5/




**Marine Heat Wave monitoring,** **Boisséson et al, ECMWF NewsLett 2021**
**Boisséson et al., in review 2022**

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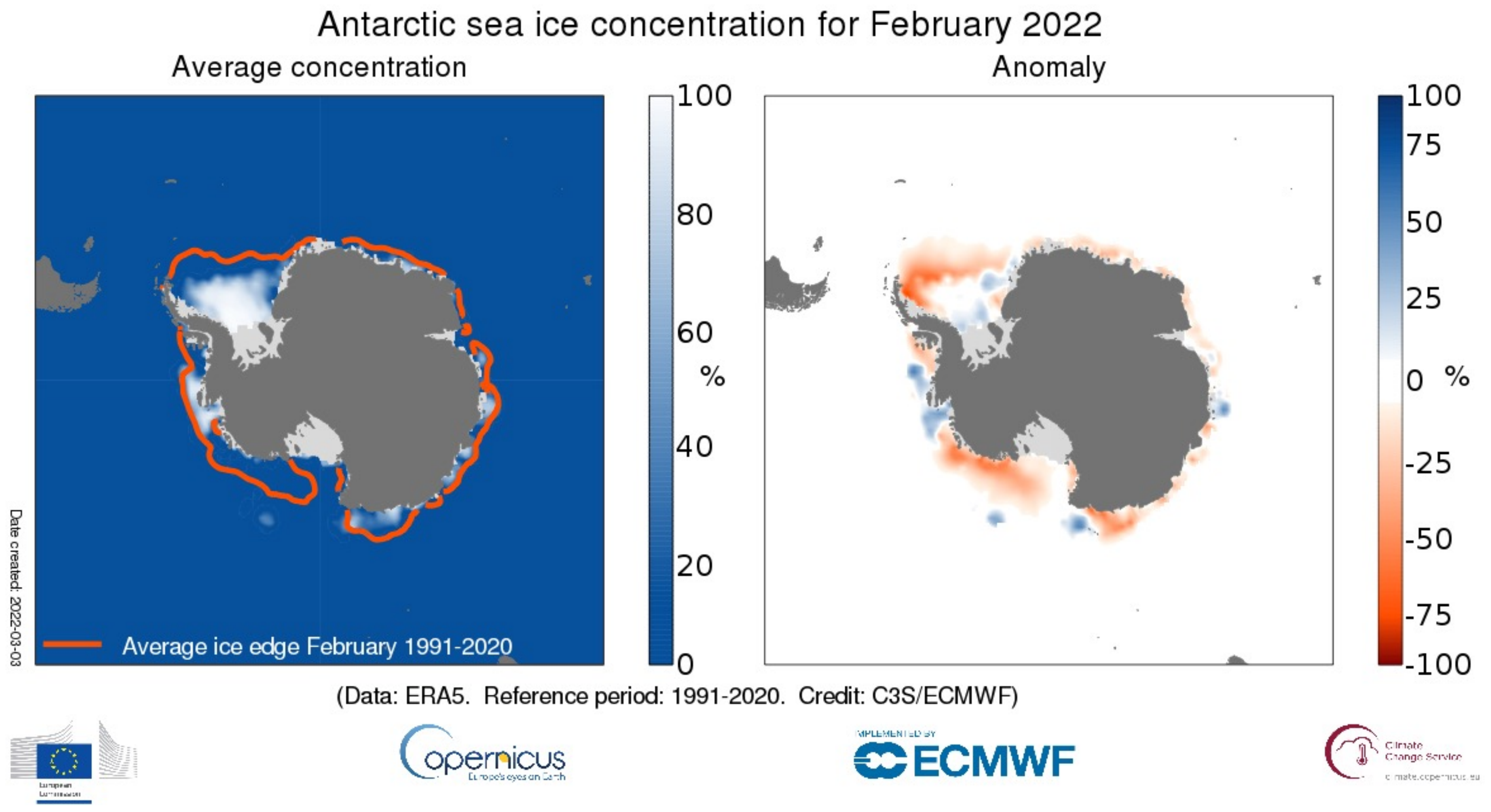
# Copernicus C3S climate monitoring

Based on **ERA5**
**Hersbach et al., QJRMS 2020**

## Climate Bulletin




Strong negative sea ice concentration anomaly in Feb 2022, 2nd lowest in this 44-year satellite record.

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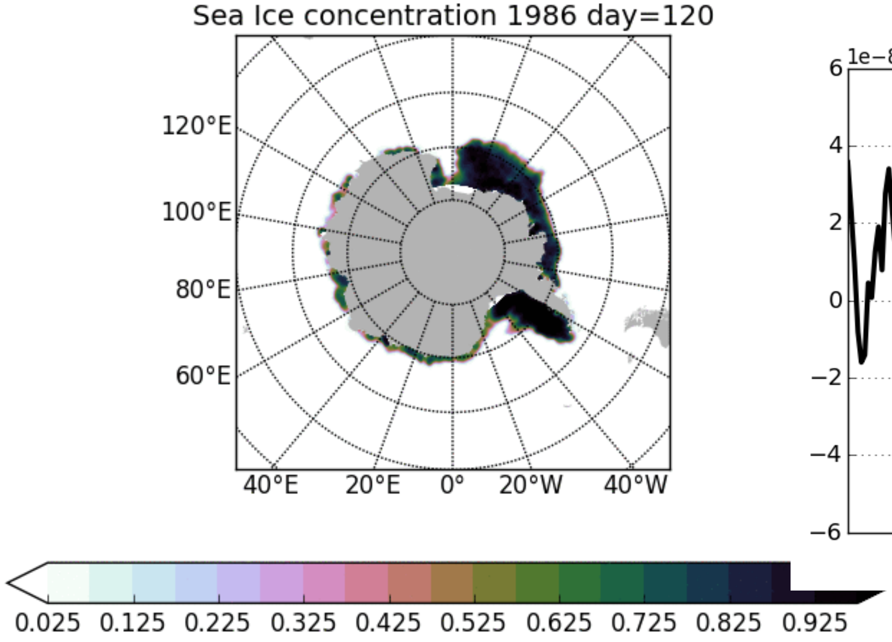
https://climate.copernicus.eu/sea-ice

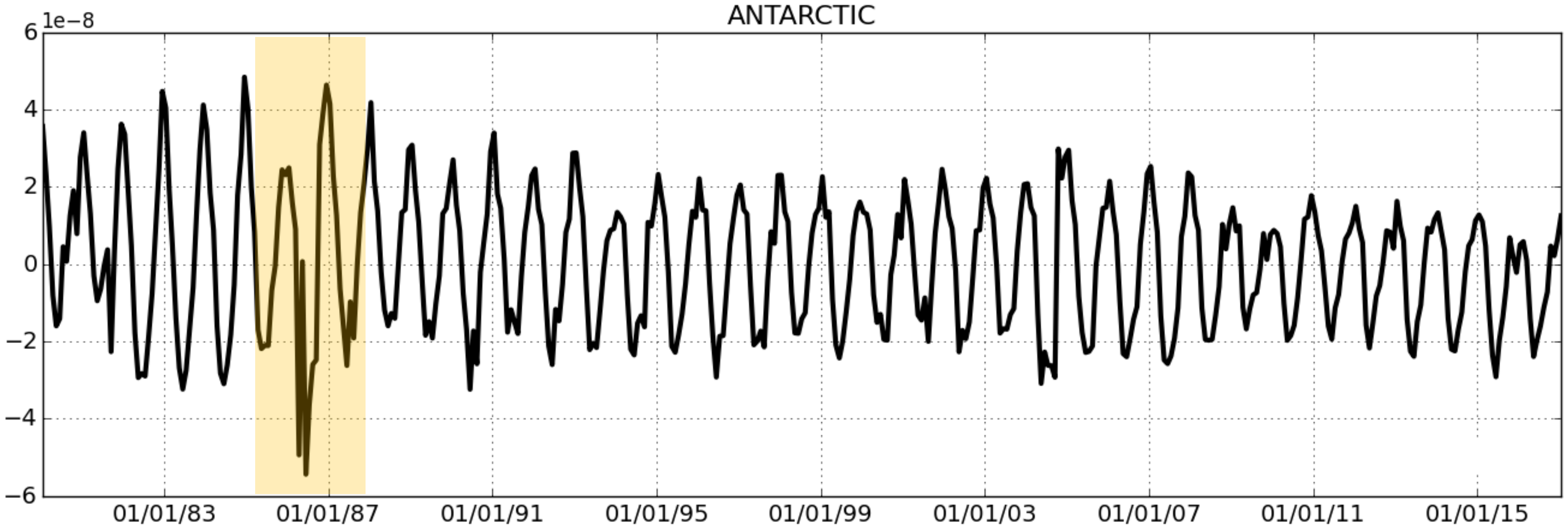
# Importance of observation consistency for reanalyses

**Sea Ice Concentration (SIC) observations missing during part of April-May 1986**

**Gap infilling in OSTIA analysis**




**ORAS5 Antarctic SIC increments**
After assimilation of OSTIA SIC




ORAS5 Antarctic sea-ice concentration show historical low in Spring 1986, which was a results of assimilating infilling SIC (no sea-ice growth) in this period.
→ Next ocean reanalysis ORAS6 (in preparation) will use level 3 OSI SAF SIC

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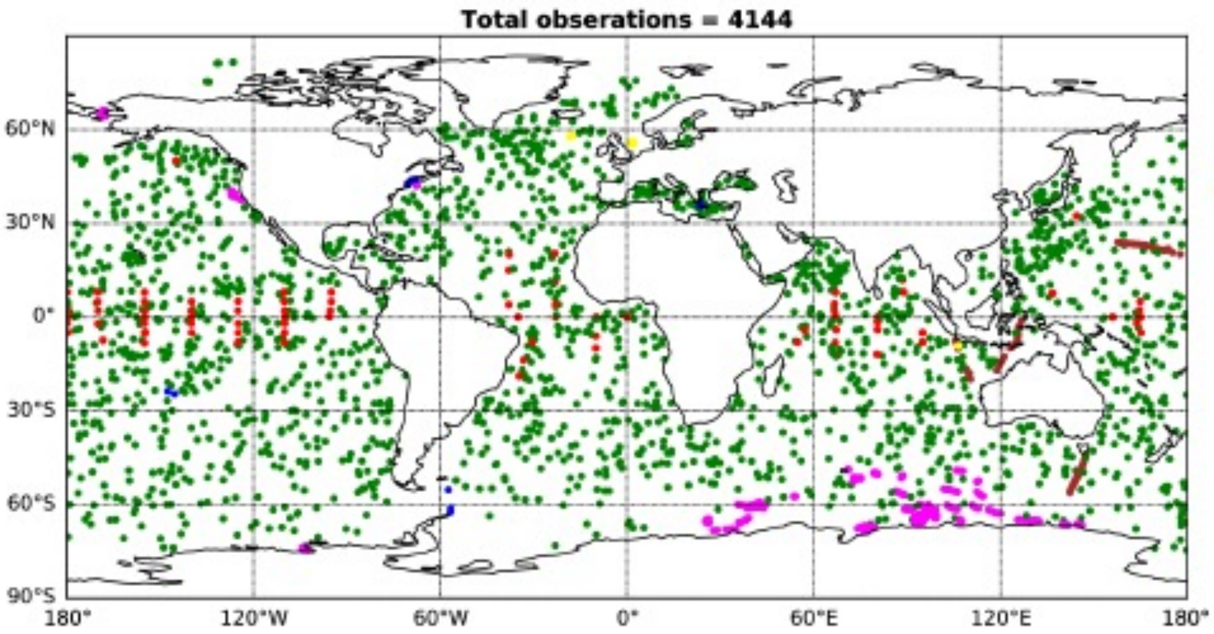
Hao Zuo

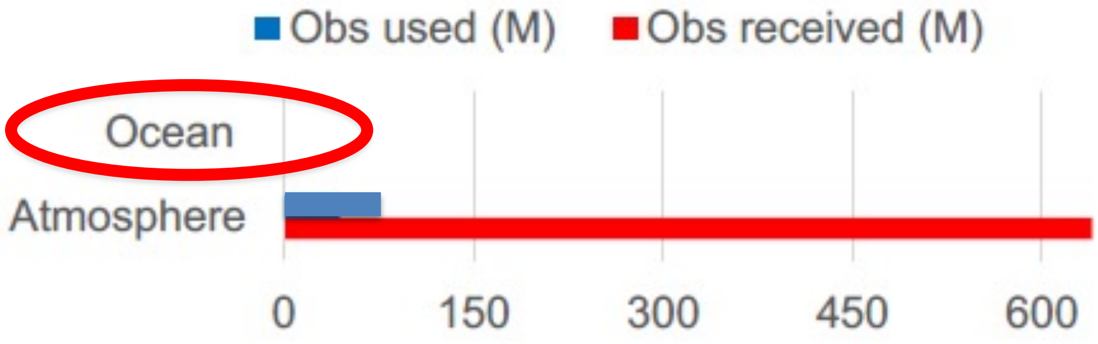
# Ocean Observing System for NWP

*Ocean in-situ observations in 5-days (After QC, Feb 2019)*

CTD:450 APB:0 UOR:0 Seaglider:124

Argo:2149 XBT:90 Mammals:931 Mooring:400




**Ocean observations (in situ + satellite) represent ~ 0.1 to 1 % of the observations received and used daily at ECMWF**

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# Ocean observation impact on ENSO prediction

The ECMWF Ocean5 system provides ocean and sea ice initial conditions for all ECMWF coupled forecasting systems (HRES, ENS, SEAS5)

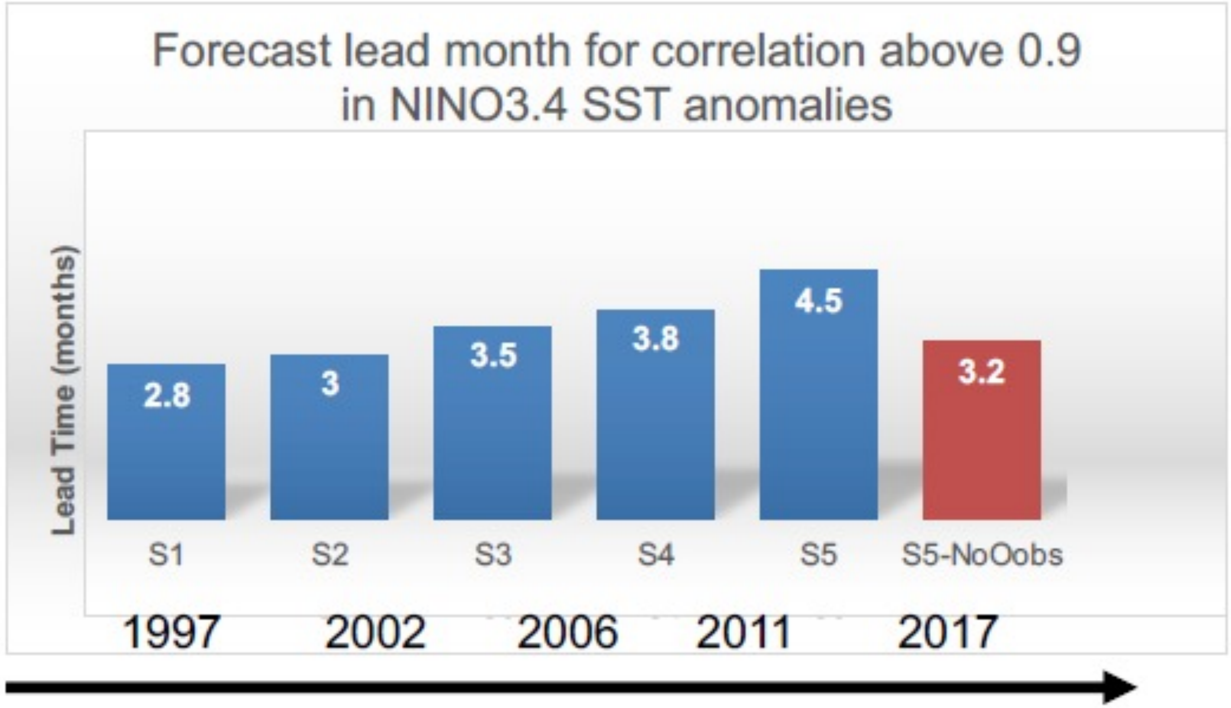



**Figure from Magdalena Alonso Balmaseda**

Ocean observations: Gain about 1.3 months in ENSO prediction.
Without ocean observations DA we would loose ~15 years of progress

ECMWF

# Impact of Sea Ice Thickness initialisation on NWP

Observing System Experiments to initialise coupled extended range forecasts

Impact of assimilation of Cryosat-2/SMOS sea ice thickness assimilation in the ocean system

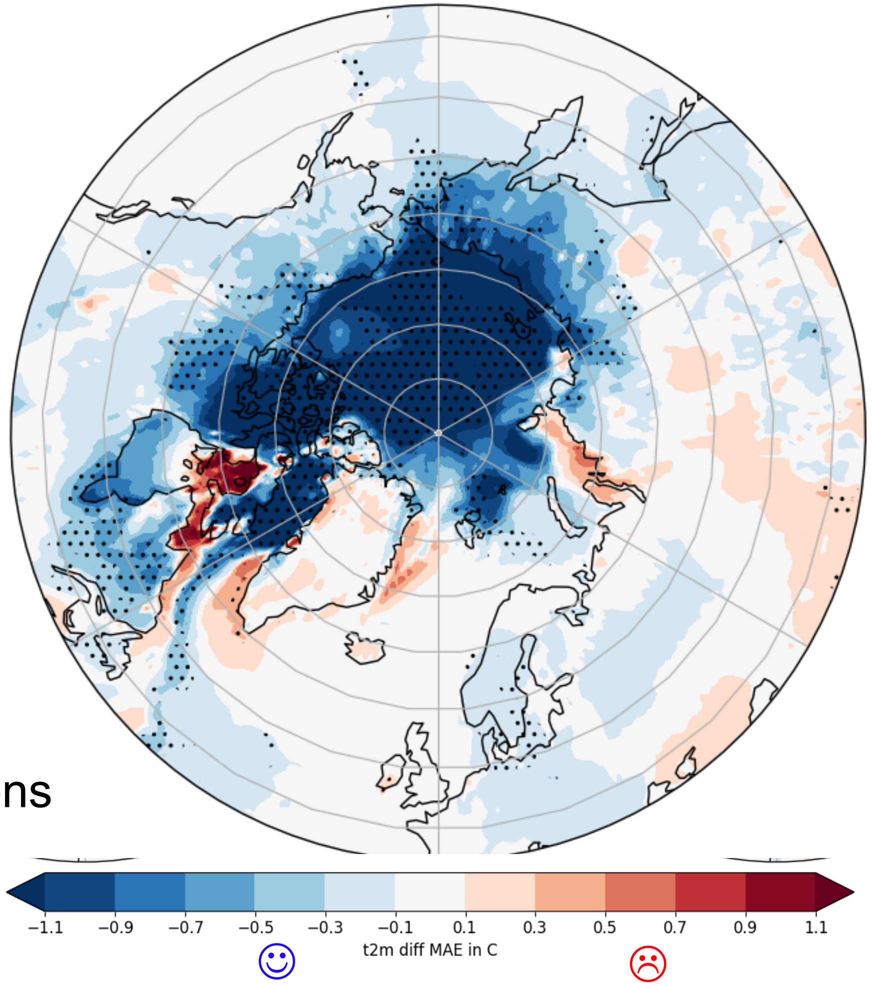
→ Significant improvement in sea ice and SST

→ Significant improvements in 2m temperature forecasts in the melt season

**Balan Sarojini et al., The Cryosphere, 2021**

- Key role of sea ice observations for NWP and reanalyses
- Synergy between altimeter and microwave data; relevance of future missions such as CIMR&CRISTAL
- ESA sea ice intercomparison project (under the WMO/GCW umbrella)

Impact on T2m (K) MAE
Forecast for SON initialised in May

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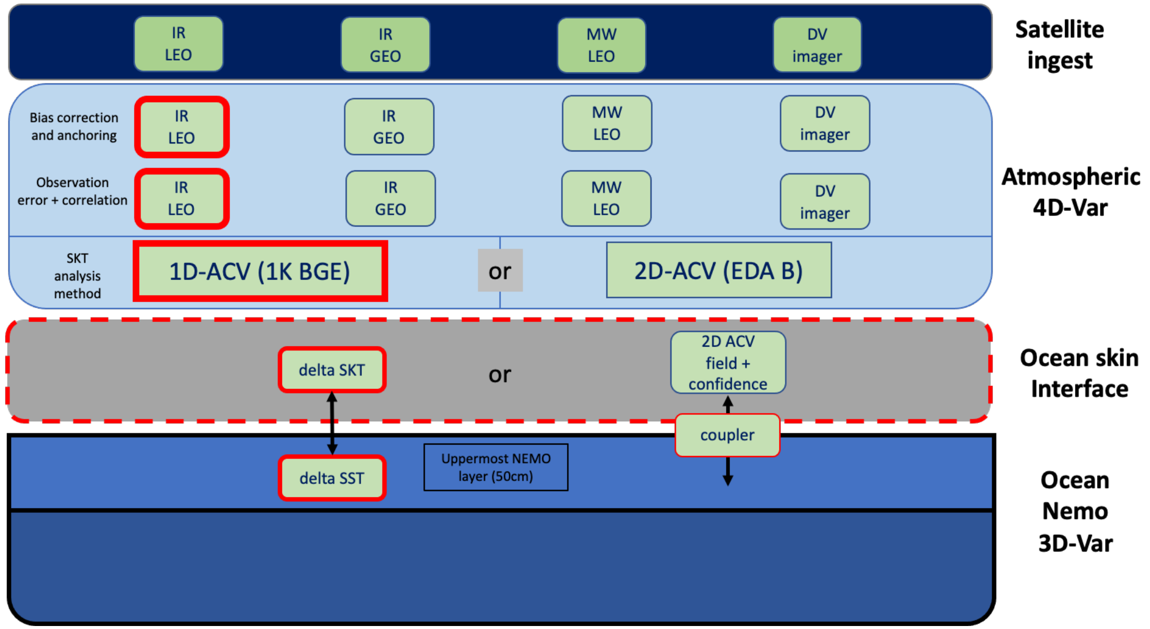
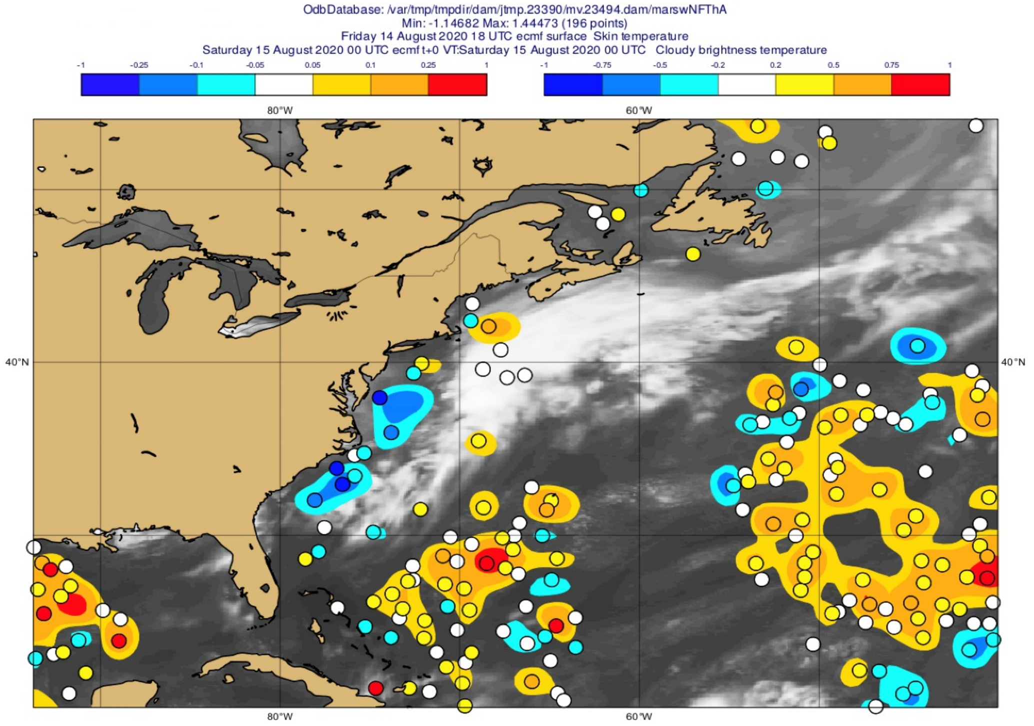
# In-house SST analysis development

Use skin Temperature derived from satellite radiances in the 4D-var Extended Control Variable (ECV) to constrain SST in the outer loop coupled DA

McNally et al.

## SST analysis options




→ Moving to consistent level 1 observations coupled assimilation to constrain atmosphere and surface temperature
→ 1D-ECV and 2D-ECV (Massart et al., GMD 2021 ) approaches investigated
→ SKT Extended Control Variable coupled DA relevant for land too

# Land observations impact: snow cover

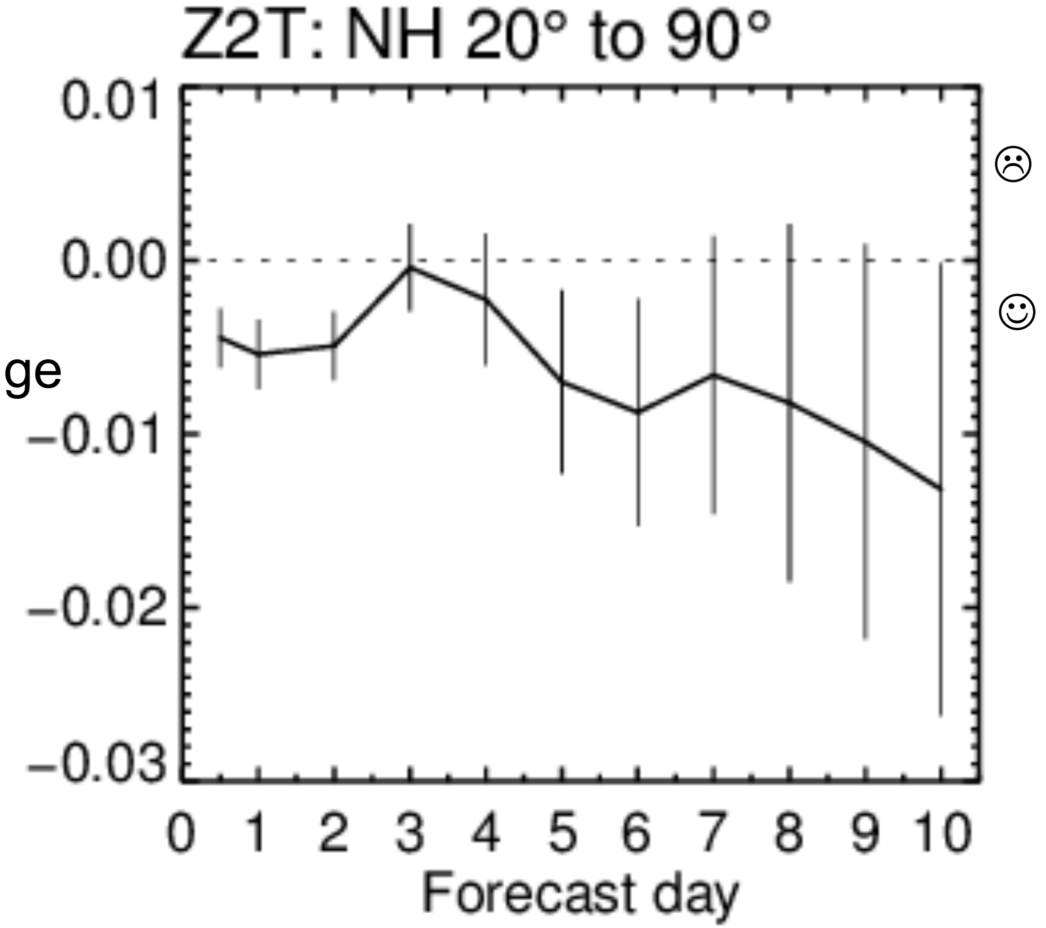
## Impact of the NOAA NESDIS IMS (Interactive Multisensor Snow and Ice Mapping System) snow cover product assimilation

- OSEs in gobal (weakly) coupled land-atmosphere assimilation system

IMS DA → T2m forecasts error reduction at medium range

**IMS assimilated in non-mountainous areas for operational NWP at ECMWF**

DJFMA 2014-2015

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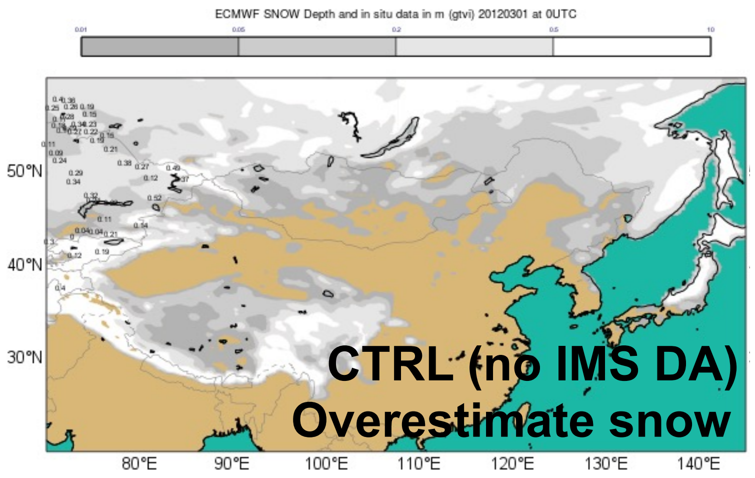
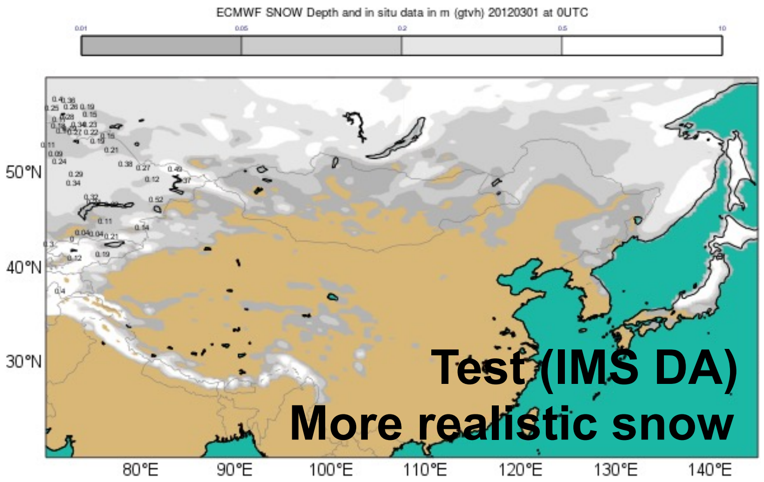
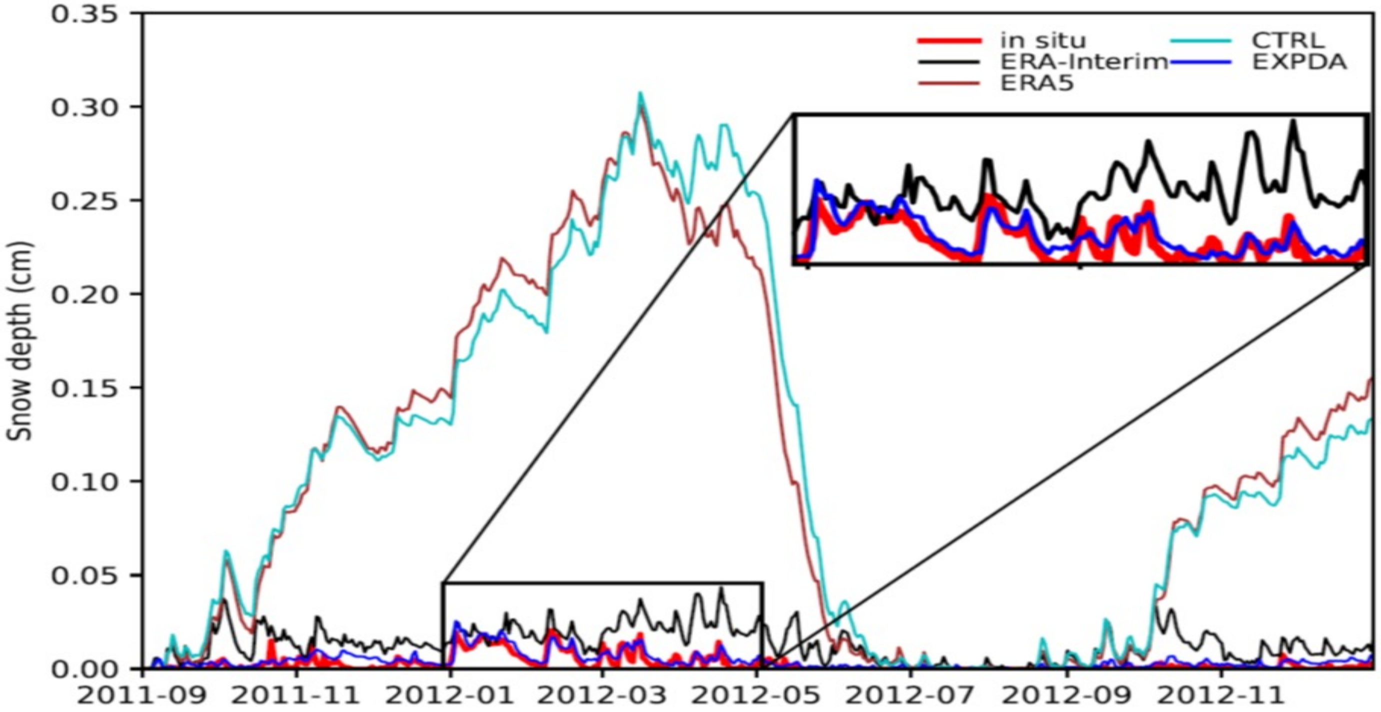
# IMS snow cover coupled data assimilation impact over the Tibetan Plateau




IMS snow cover assimilation removes snow and improves snow depth

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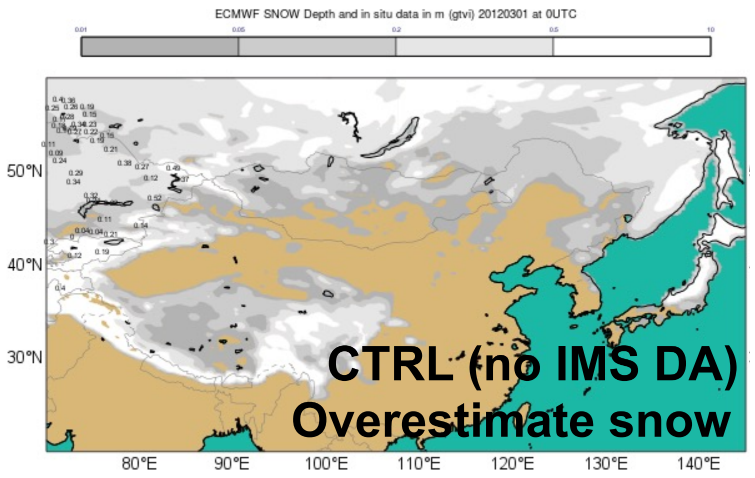
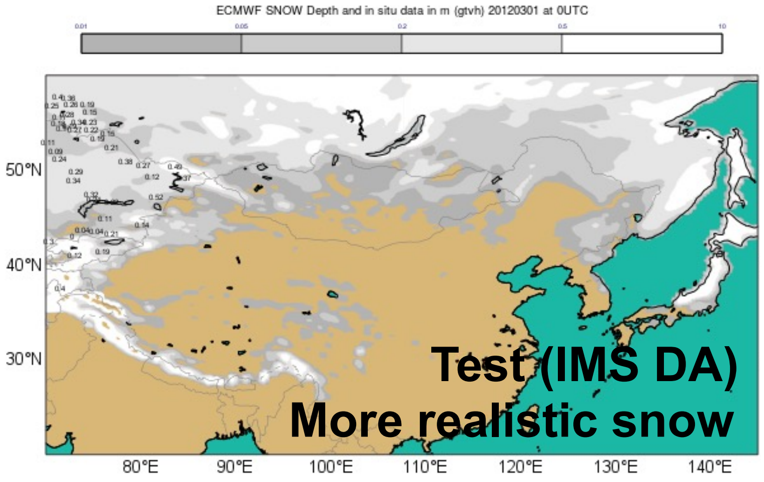
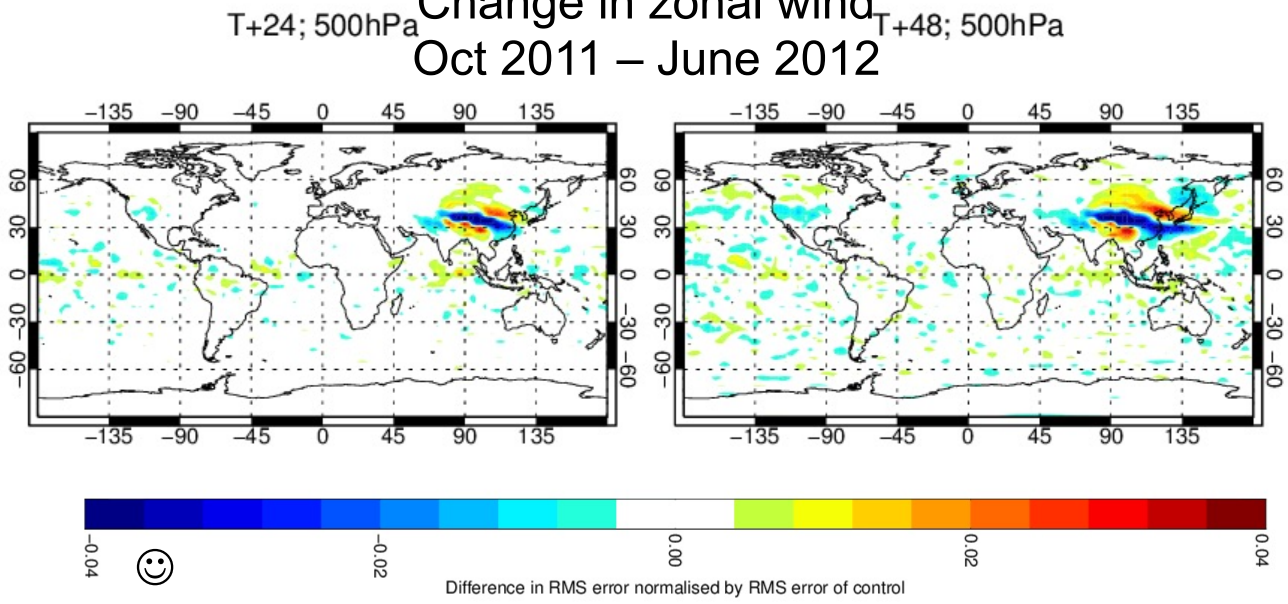


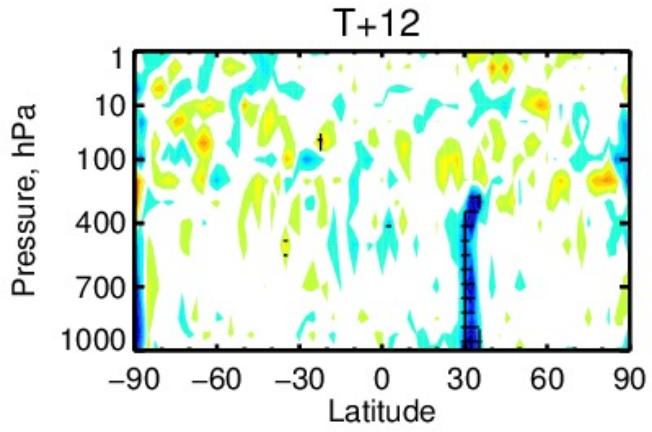



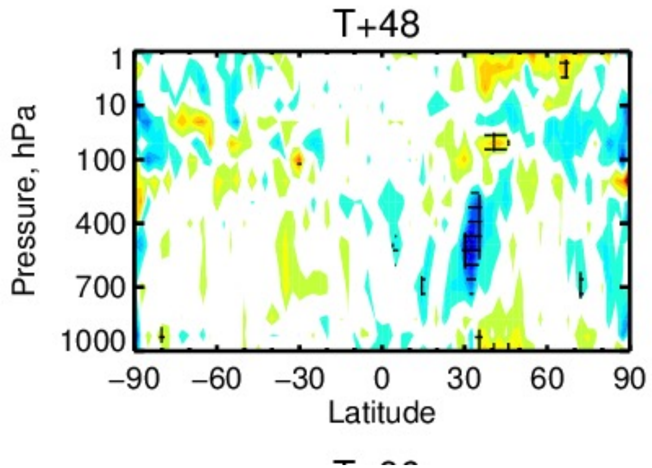

Impact on albedo and momentum
→ Modifies the jet circulation

Change in zonal wind
Oct 2011 – June 2012



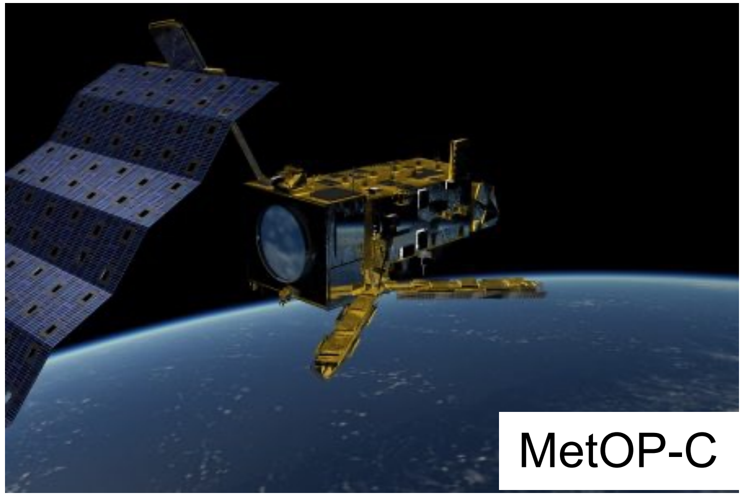

Change in humidity FC error
Oct 2011 – June 2012



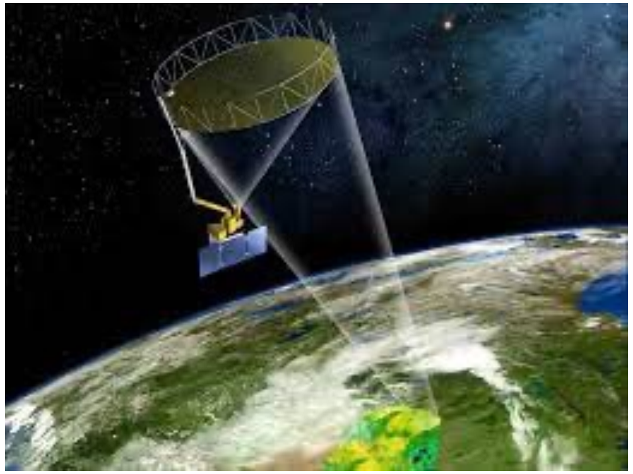
# Soil moisture satellite observations used operationally

**Active microwave data:**
**ASCAT**: Advanced Scatterometer
On MetOP-A  (2006-), MetOP-B (2012-), MetOP-C (2018-)
C-band (5.6GHz) backscattering coefficient
EUMETSAT Operational mission




**Passive microwave data:**
**SMOS**: Soil Moisture & Ocean Salinity (2009-)
L-band (1.4 GHz) Brightness Temperature
ESA Earth Explorer, dedicated soil moisture mission
(Munoz-Sabater et al., GRSL, 2012)


**SMAP**
L-band TB  2015-
NASA Dedicated
soil moisture mission



Scatterometer soil moisture also used in ERA5
(ERS-SCAT, Metop/ASCAT)

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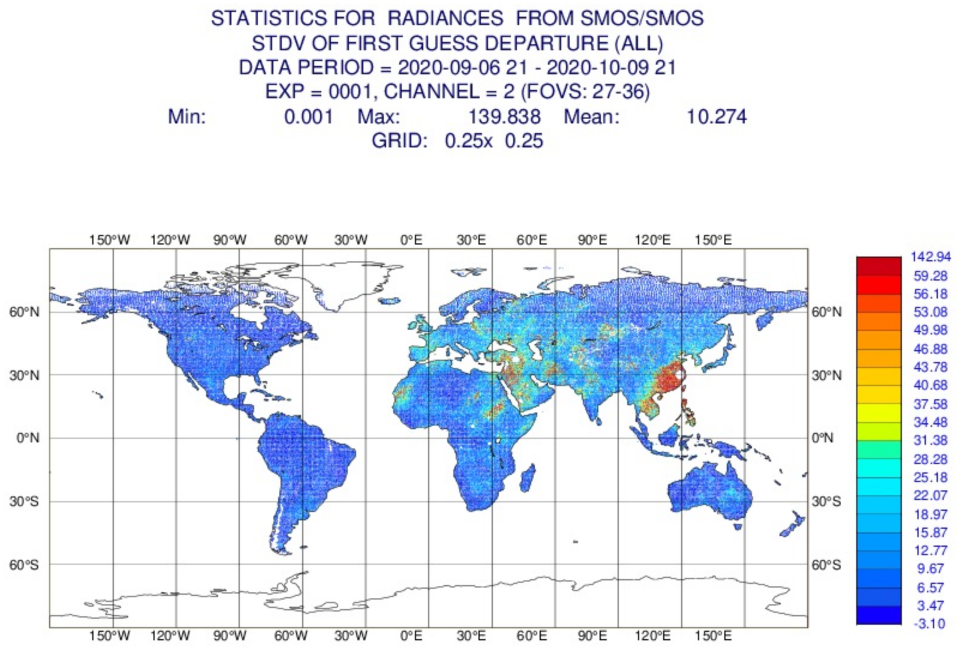
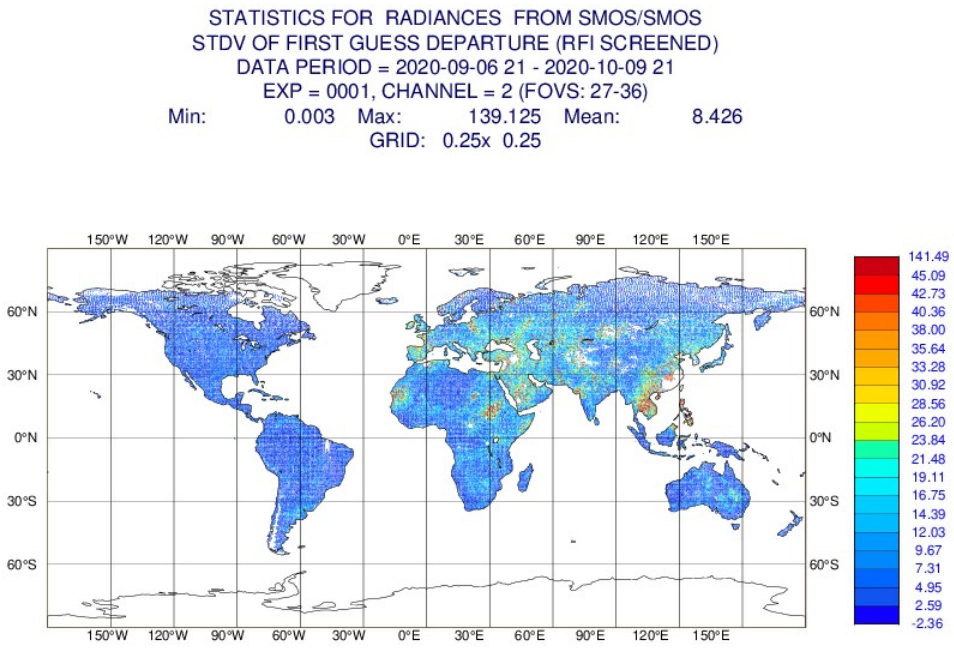
# Observation monitoring and quality control

**SMOS brightness temperature operational monitoring**

- Summer 2020: a large area of RFI (Radio Frequency Interference) contamination over South-East China
- Improved screening does a better job of filtering it out but still not perfect
    - Need for further improvements in RFI filtering flags
    - **Importance of <u>quality control</u>** Weston et al., RS 2021




Basic RFI screening




Stronger RFI screening

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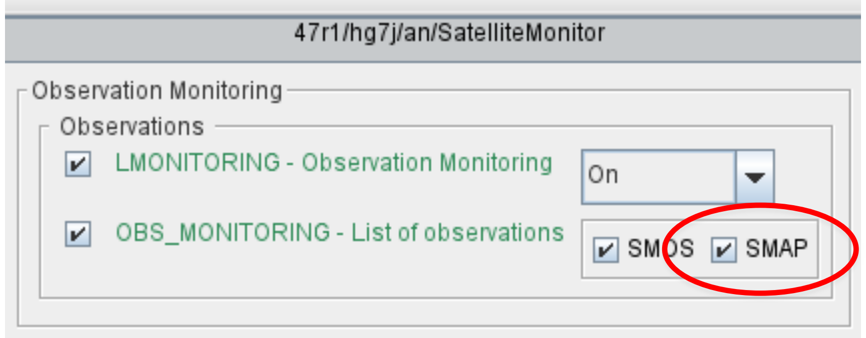
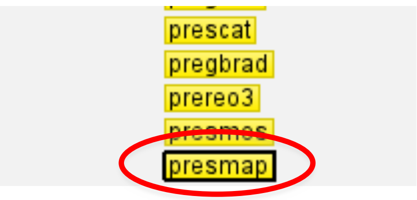
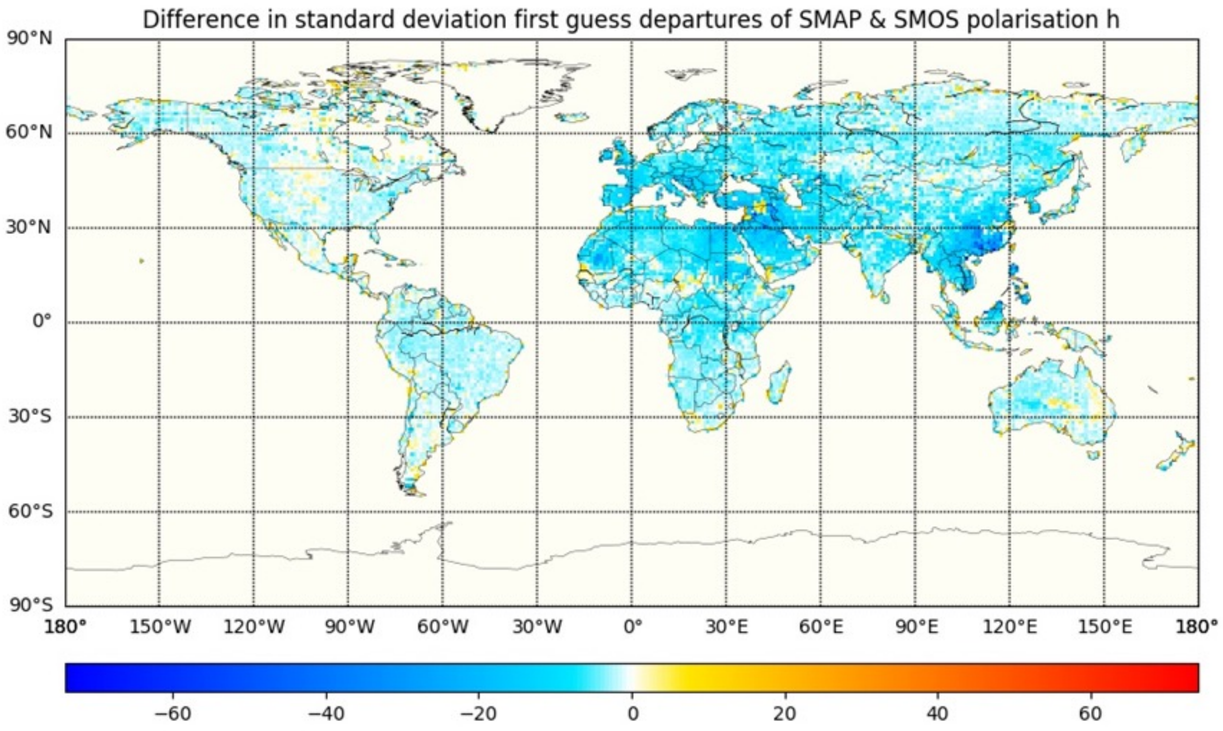
# SMAP L-band observations

# Operational IFS monitoring since May 2021




- Set-up operational NRT acquisition
- Scripts suite and prepIFS changes complete
- SMAP Observation interface (Obs Data base, ODB)
- Script and Fortran changes
- Suite definition and prepIFS
- Monitoring webpage update
- Next: SMAP assimilation evaluation




**→ Consistent work flow than for atmospheric observations**

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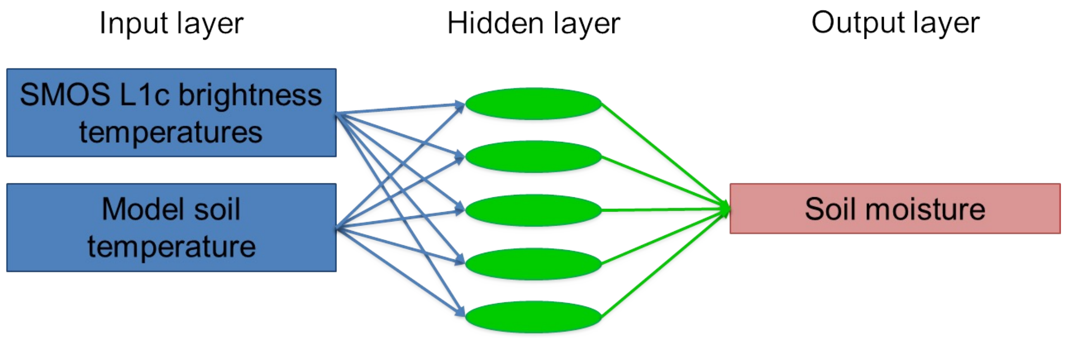
Pete Weston

# SMOS neural network soil moisture assimilation

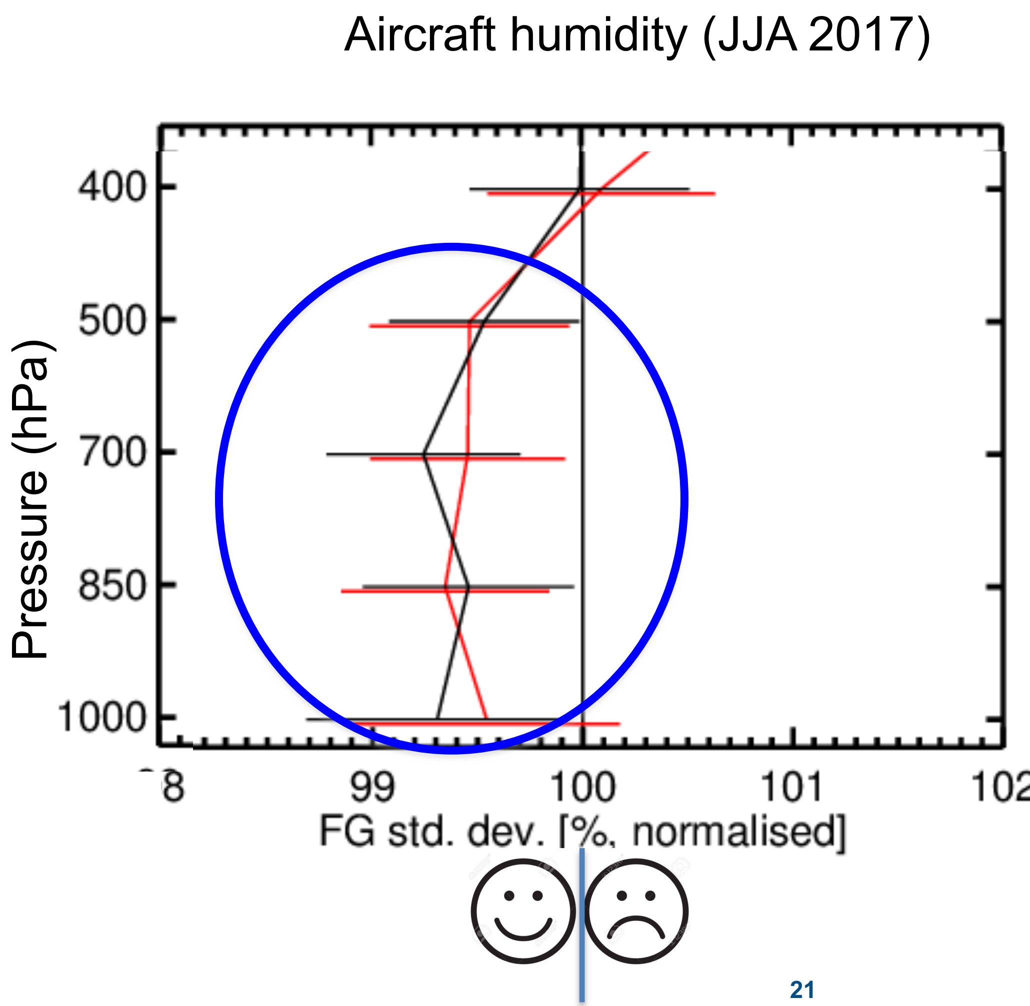



Rodriguez-Fernandez et al., HESS 2017, Rem. Sens 2019

A priori training of the SMOS neural network processor
-> retraining when L1Tb or IFS soil change
Online training possibilities?

Further explore ML/AI for forward modelling both for passive and active MW data (e.g. ASCAT: Aires et al, QJRMS 2021)

**NWP**
**SMOS soil moisture impact**

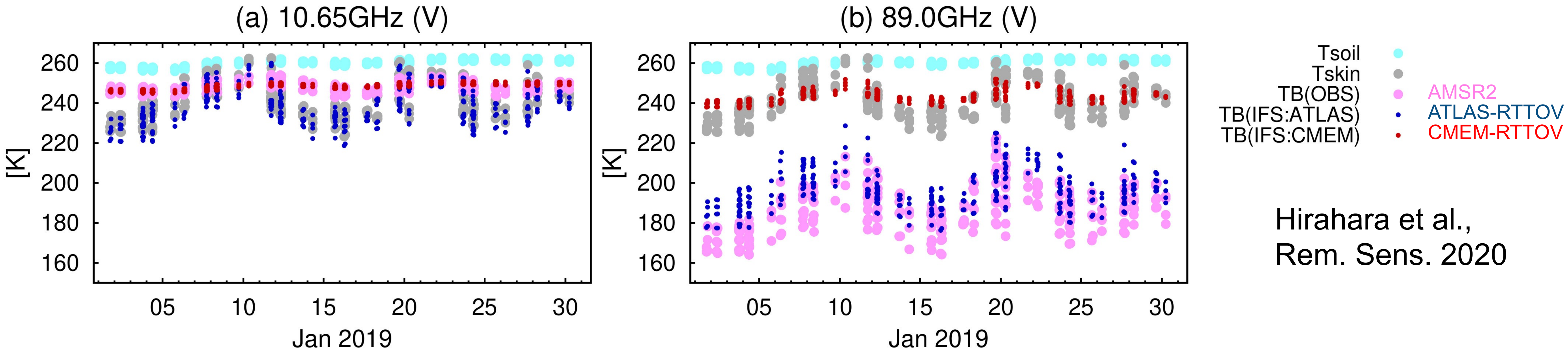


# Towards assimilation of surface-sensitive satellite data over snow covered areas

- Interface between CMEM and RTTOV in the IFS for surface sensitive observations
- Multi-layer snow radiative transfer scheme (HUT, Lemmetyinen et al., 2010) in CMEM

→ **support developments to extend the "all-sky" to "all-sky" and "all-surface" approach**

## CMEM-RTTOV coupling:




Hirahara et al., Rem. Sens. 2020

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# Summary (1/2)

- Progressive implementation of coupled assimilation at ECMWF for operational NWP and future generations of reanalyses (NWP, Copernicus Services, and high resolution Destination Earth)

- Relevance of interface observations, e.g. Snow (cover, water equivalent, depth), sea ice (concentration, thickness), snow on sea ice, SST for NWP and reanalysis

- Challenges of Earth System approach for NWP, e.g. Coupling through the observation operator, e.g. SST, snow surfaces, → opportunities to enhance the exploitation of current and future satellite data

# Summary (2/2)

- Transition to lower level (level 1) products assimilation: key for coupled assimilation to enhance assimilation of observations that are sensitive to the surface
  - Further work on skin temperature DA over ocean and extend to land
  - Investigate multivariate soil and vegetation analysis (consistent water and $CO_2$)
  - Further developments on forward operator coupling, integrating ML/AI to tackle challenges of radiative transfer over complex surfaces in support of an all-surface approach

- **Earth system approach → extend to more components**: consistency with atmospheric composition work, extension to river and flood forecast system, <u>consistent water-energy-carbon cycles assimilation</u> (link Copernicus Services C3S, CMEMS, CEMS, CAMS)

## Special Collection Quarterly Journal of The Royal Meteorological Society
# "Coupled Earth system data assimilation"

- Announced at the first Joint WCRP-WWRP Symposium on Data Assimilation and Reanalysis

- We invite contributions on coupled assimilation developments for research and operational applications.
  We welcome papers that address methodological aspects of coupled assimilation as well as scientific investigations on coupling degrees and impact studies.

- Submission deadline: 31 December 2022

https://rmets.onlinelibrary.wiley.com/