IESWG meeting
5 April 2022

Consistent exploitation of Earth system observations in coupled assimilation systems

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Thanks to: Mohamed Dahoui, Stephen English, Gianpaolo Balsamo, Gabriele Arduini, and many others

ECMWF EUROPEAN CENTRE FOR MEDIUM-RANGE WEATHER FORECASTS

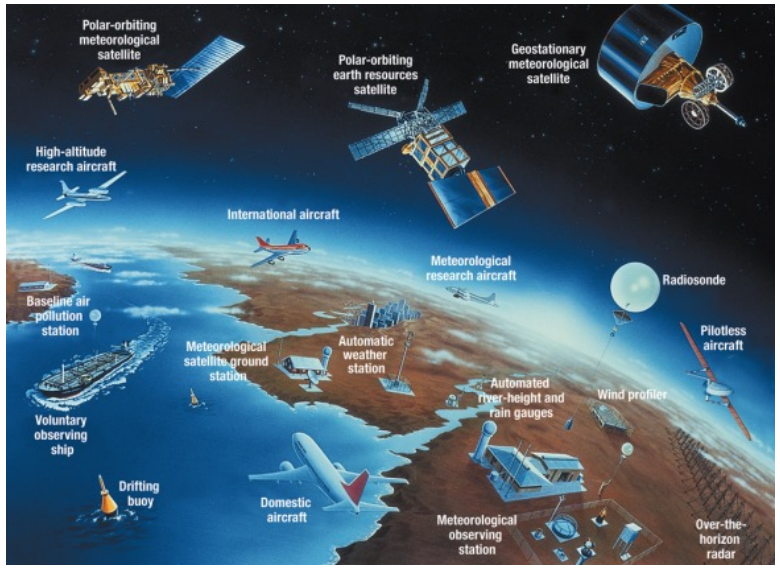
Earth system assimilation: ECMWF strategy

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

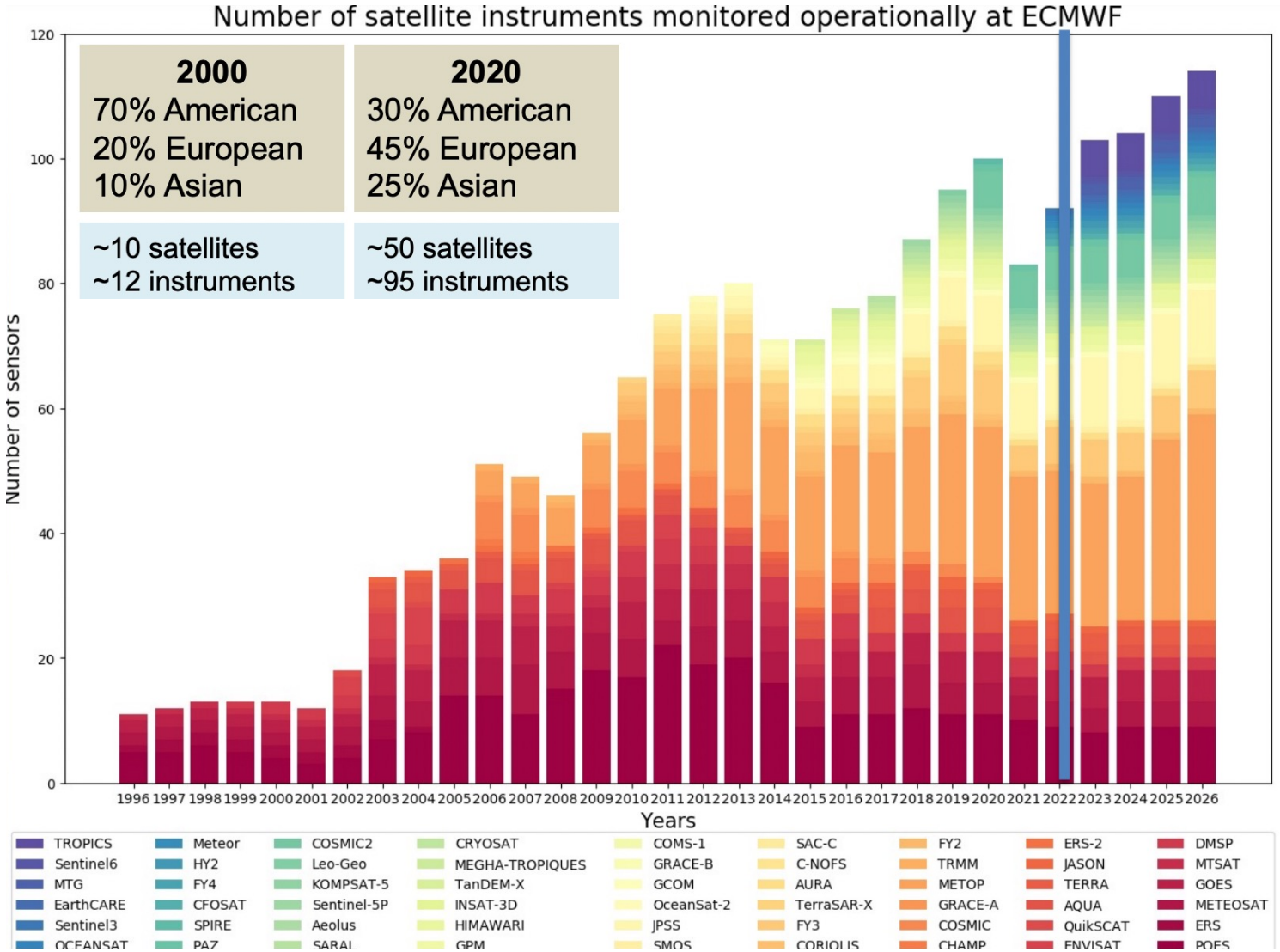
Earth system assimilation of current and future observations



(Image copyright WMO)

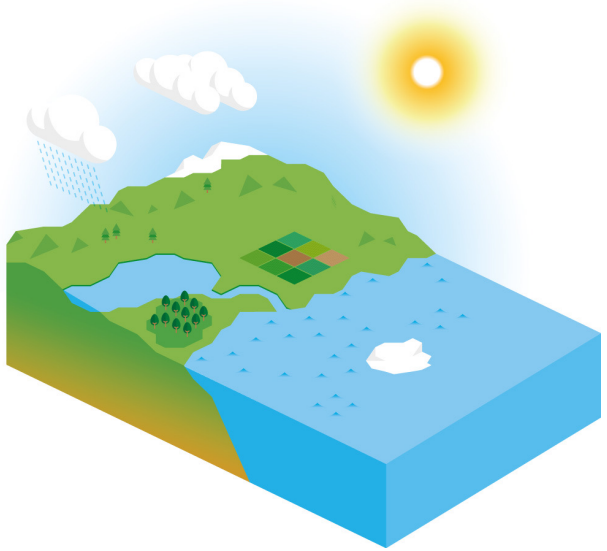
Revolution in upcoming satellite data:

- Private sector
- Diversity of space agencies
- MTG, EPS-SG, Sentinels

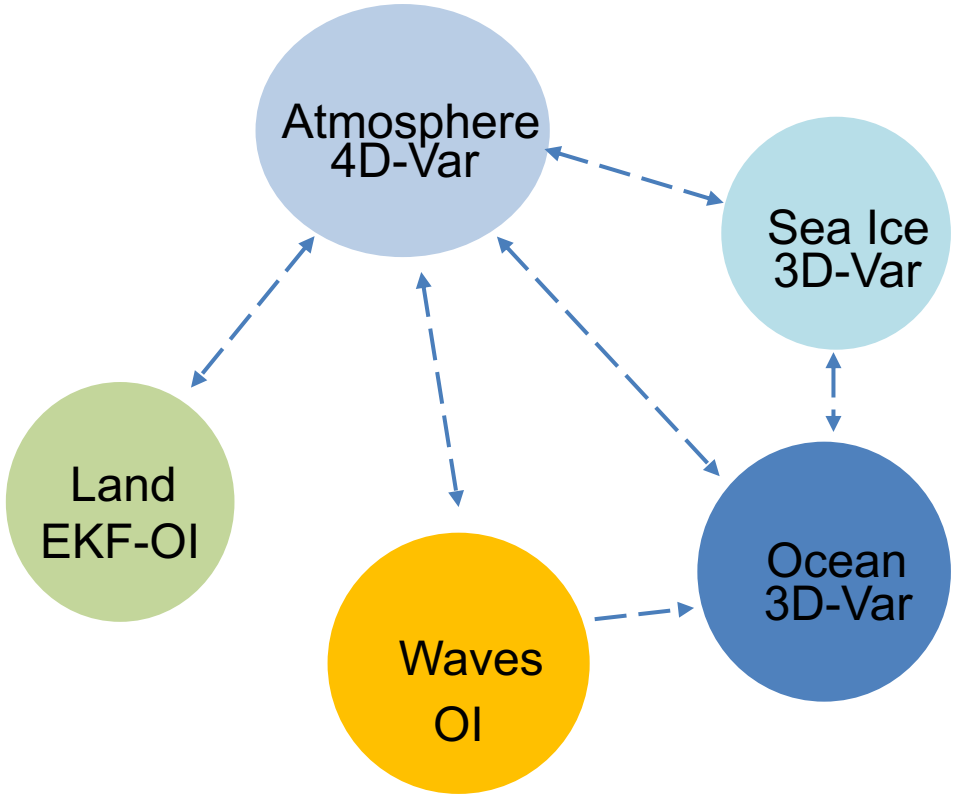


(Thanks to Mohamed Dahoui and Steve English)

Earth system approach



Integrated Forecasting System (IFS)



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

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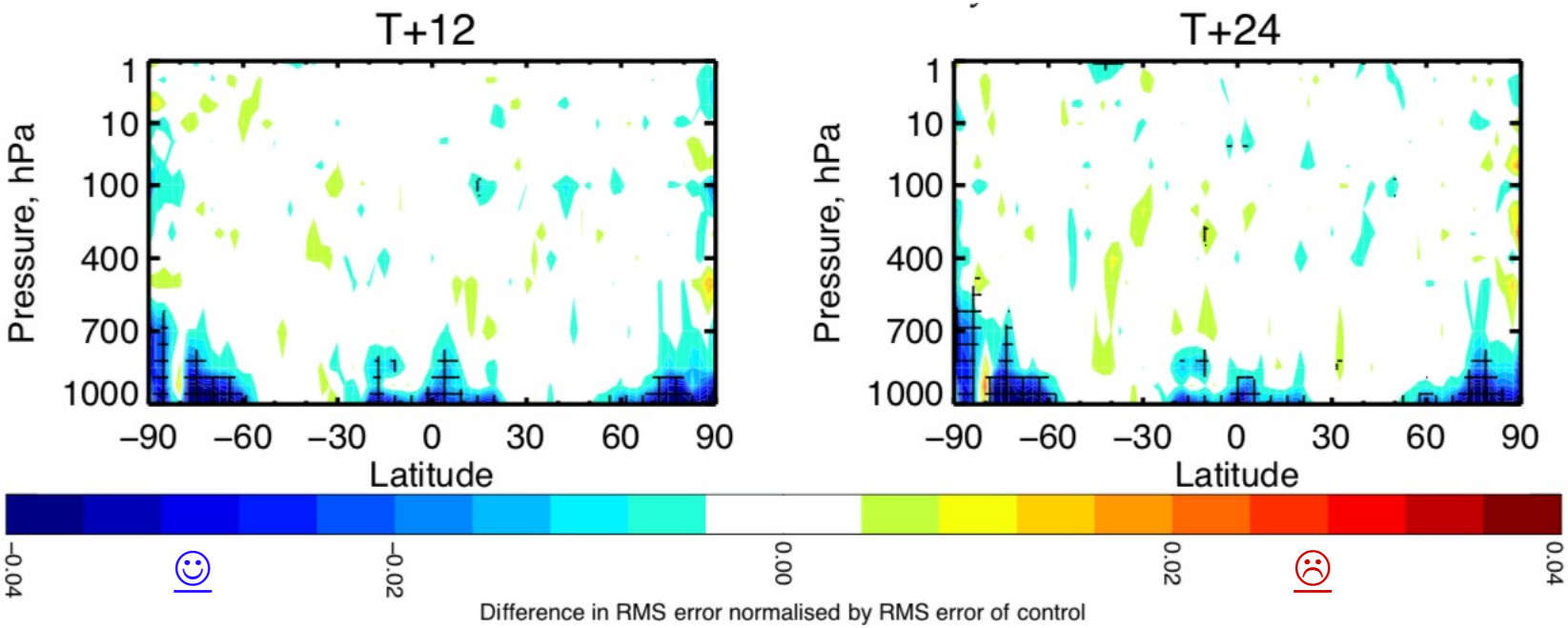
Ocean-atmosphere weakly coupled assimilation through sea ice and SST

June 2017-May 2018

Impact on Temperature Forecasts



(b) dRMSE of temperature (K)

(June 2017 to May 2018)

Normalized RMSE difference
(coupled DA – uncoupled DA)

Browne et al., Remote Sensing, 2019

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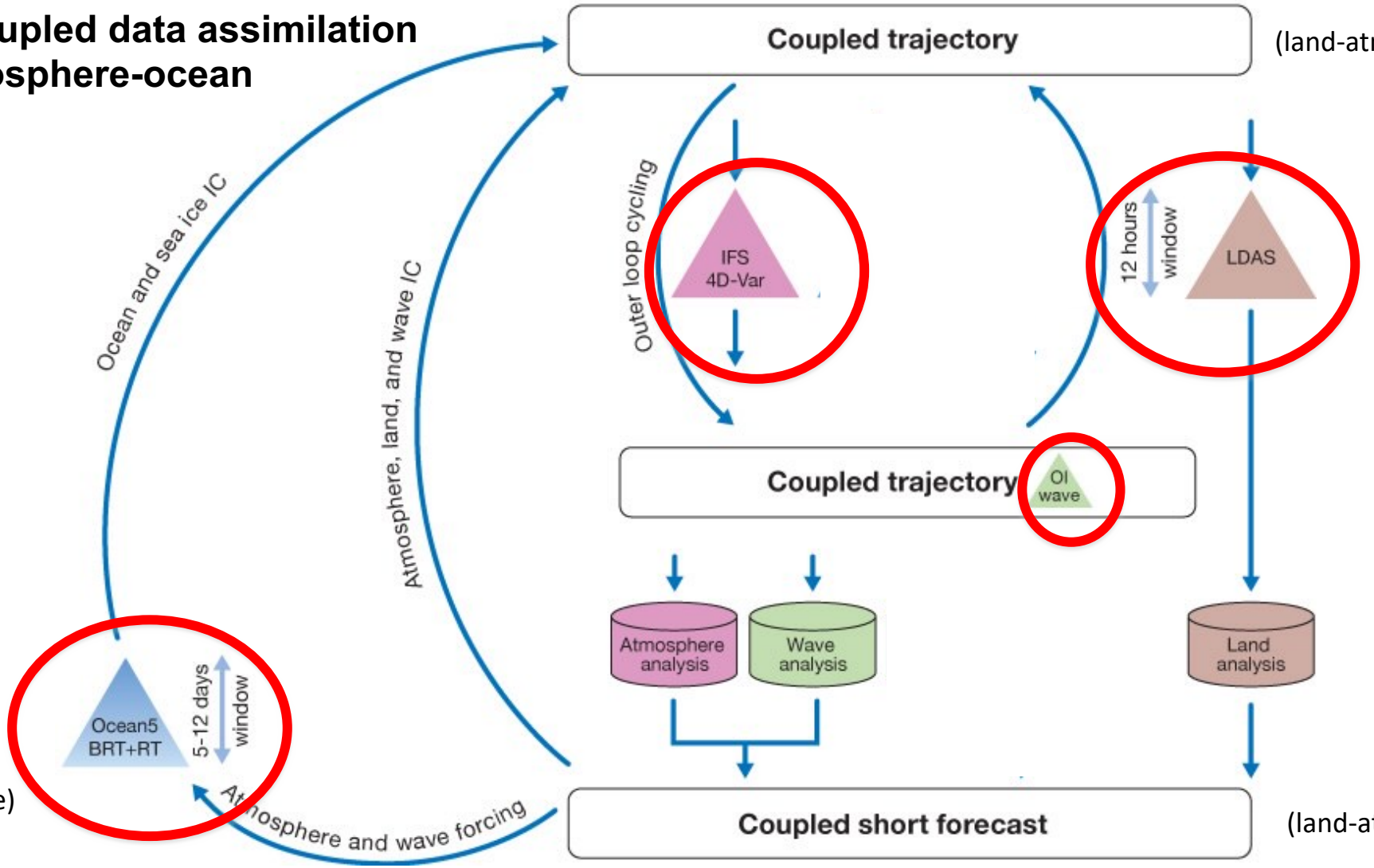
Coupled Assimilation for operational NWP at ECMWF

Weakly coupled data assimilation
Land-atmosphere-ocean



(ocean and sea ice)

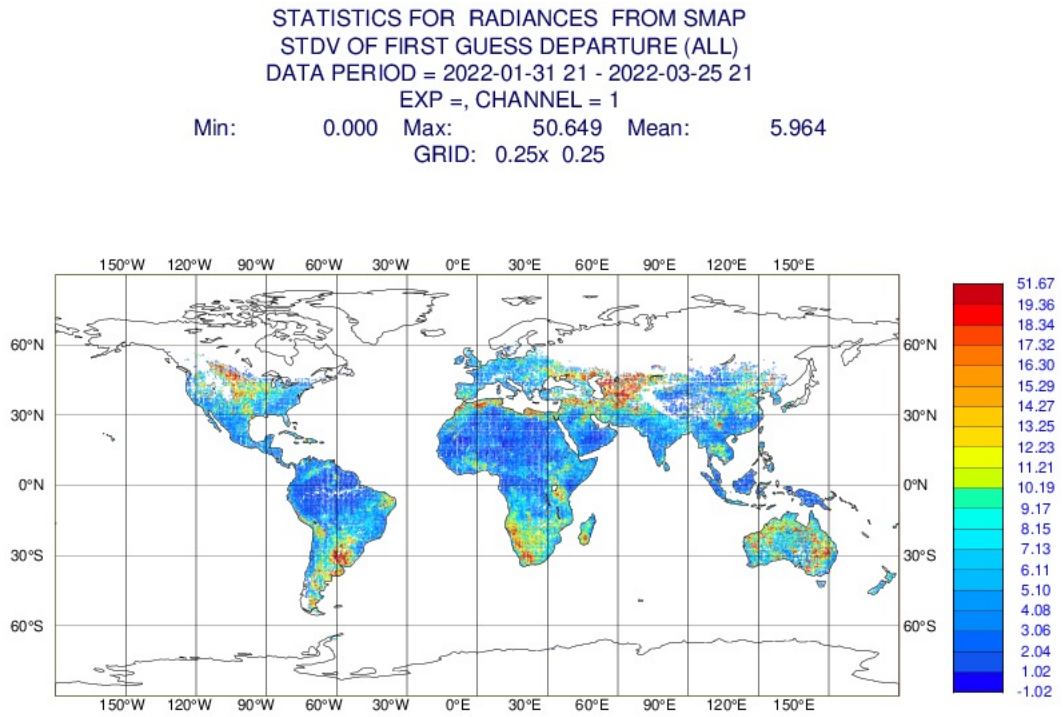
Earth system observations acquisition and monitoring

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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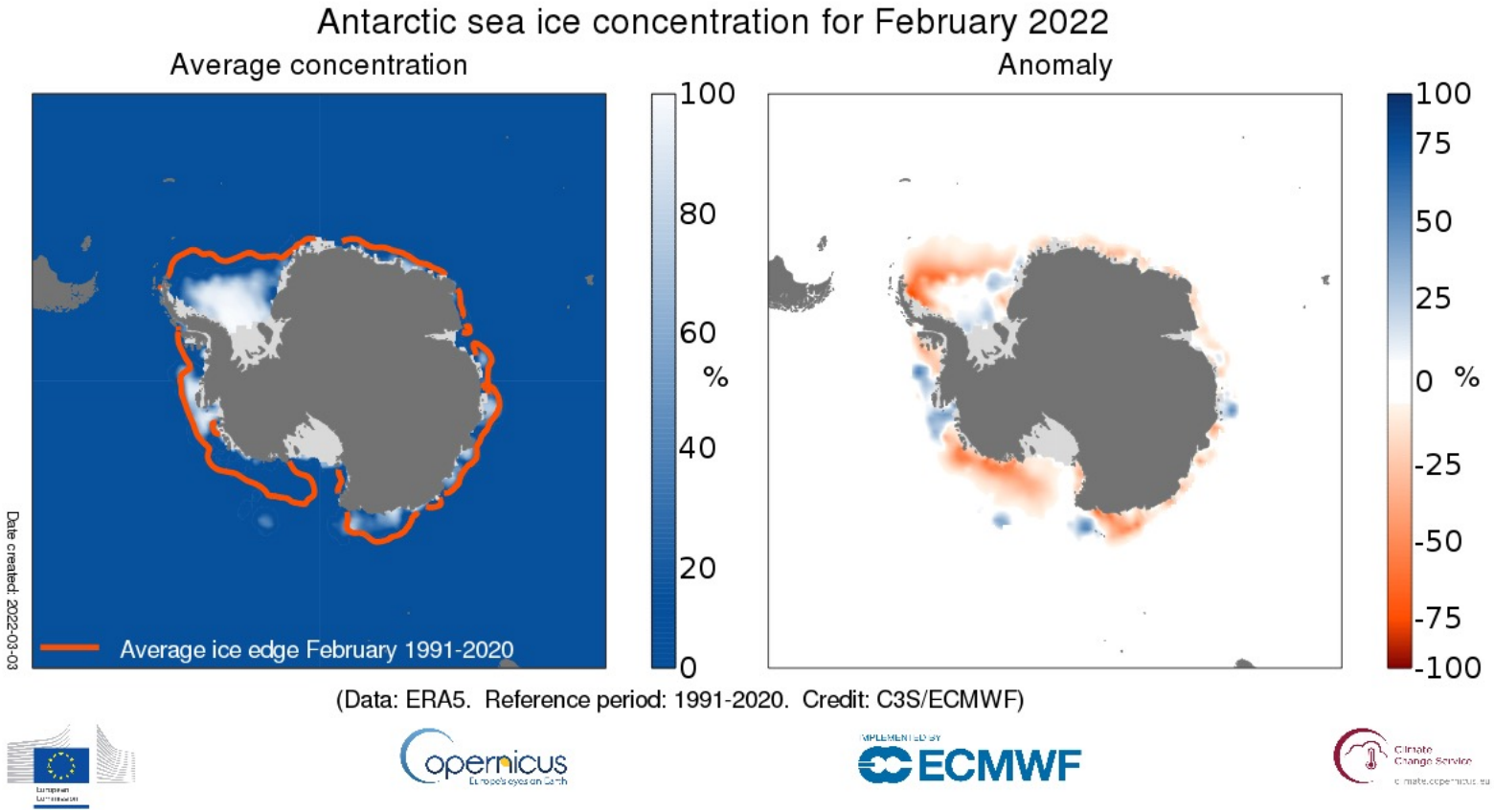
Copernicus C3S climate monitoring

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

Climate Bulletin



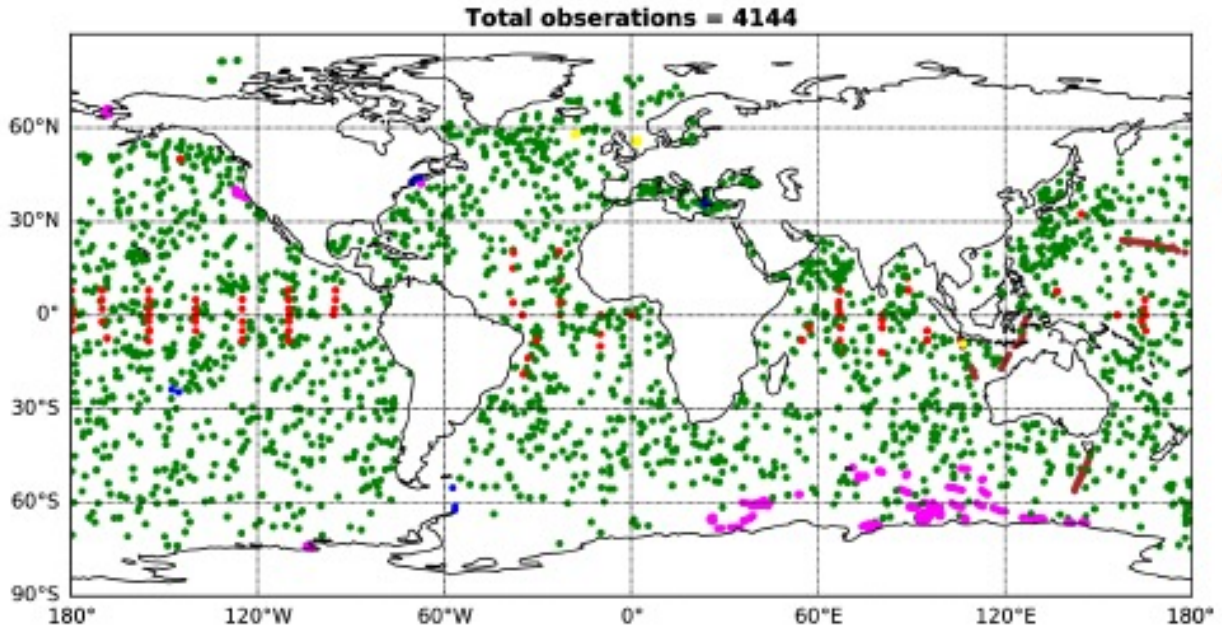
Strong negative sea ice concentration anomaly in Feb 2022, 2nd lowest in this 44-year satellite record.

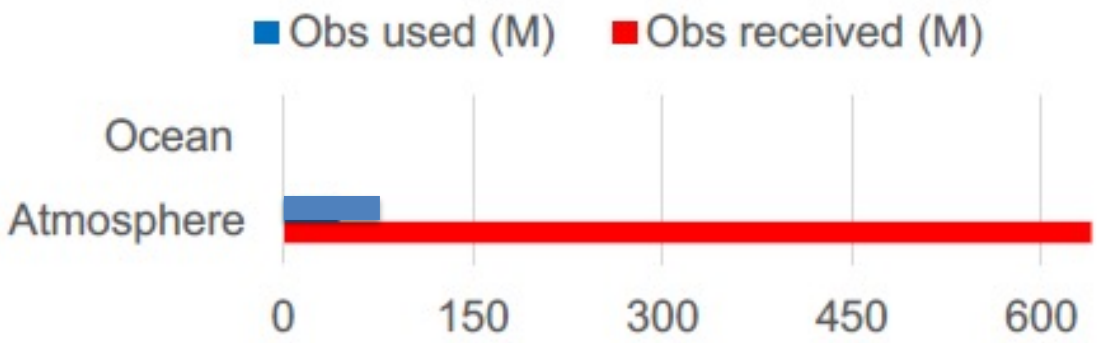
https://climate.copernicus.eu/sea-ice

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)

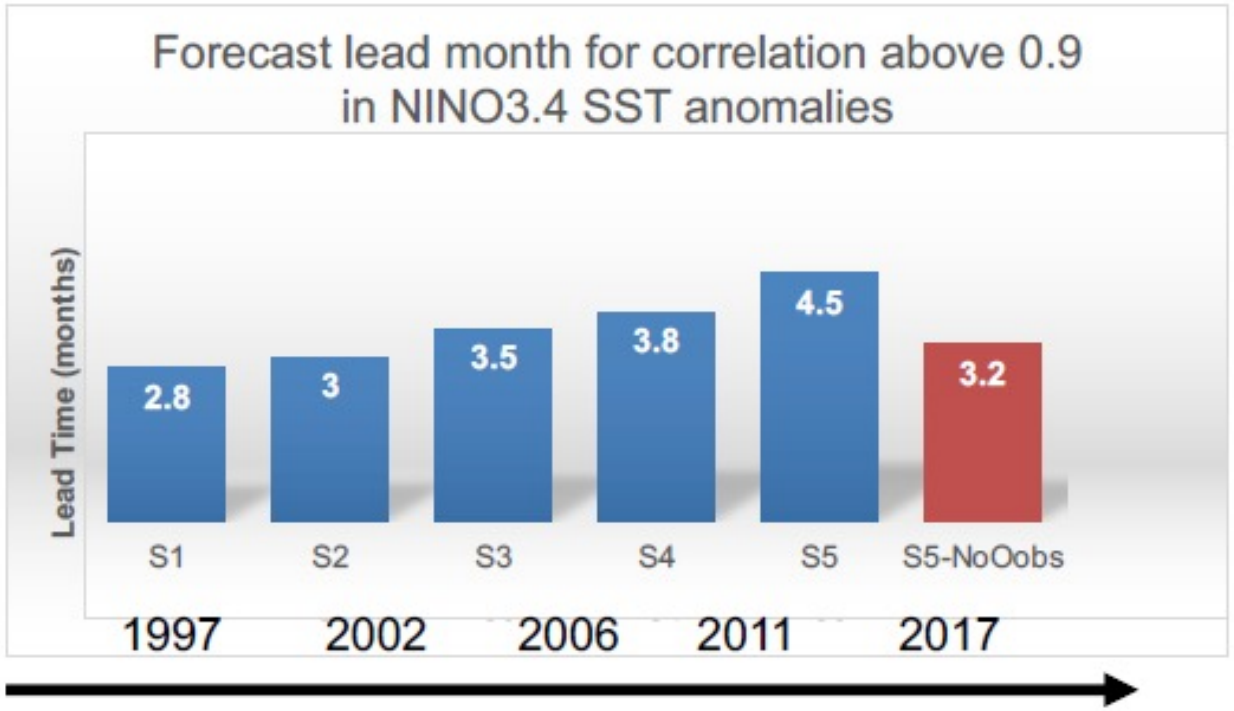

Figure from Magdalena Alonso Balmaseda

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

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Impact of Sea Ice Thickness initialisation on NWP

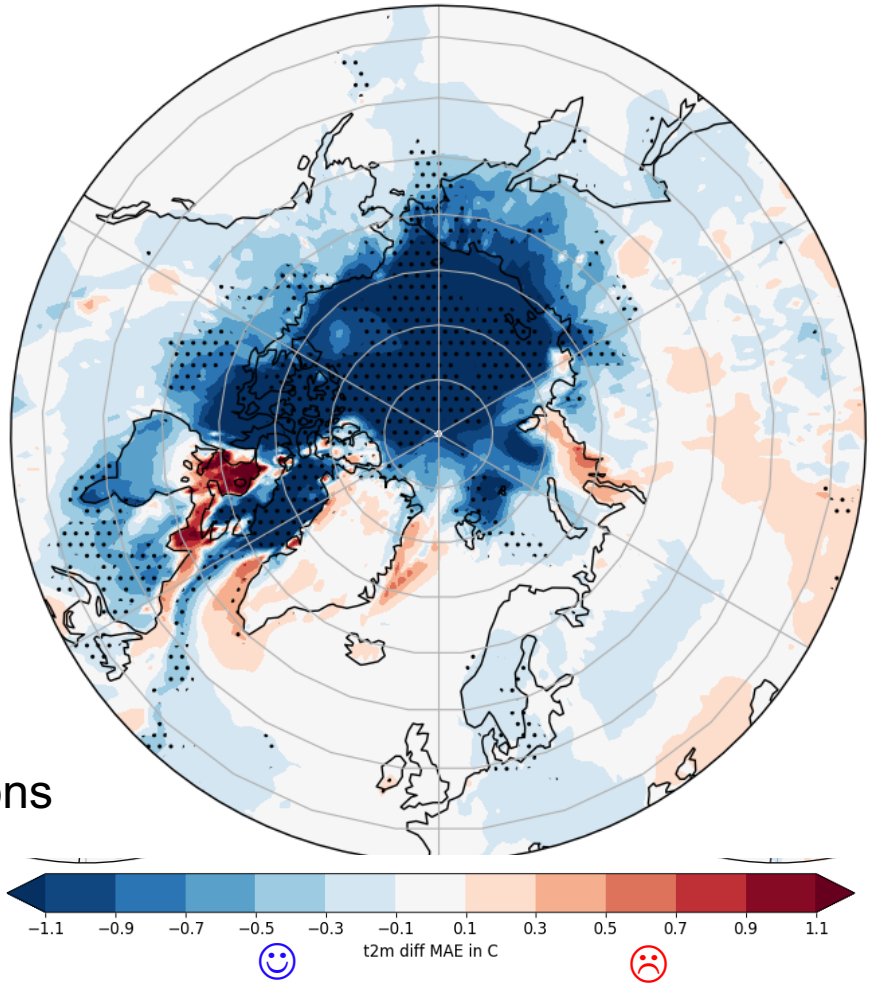
Observing System Experiments to initialise coupled extended range forecasts

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

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



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)

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Land observations impact: snow cover

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

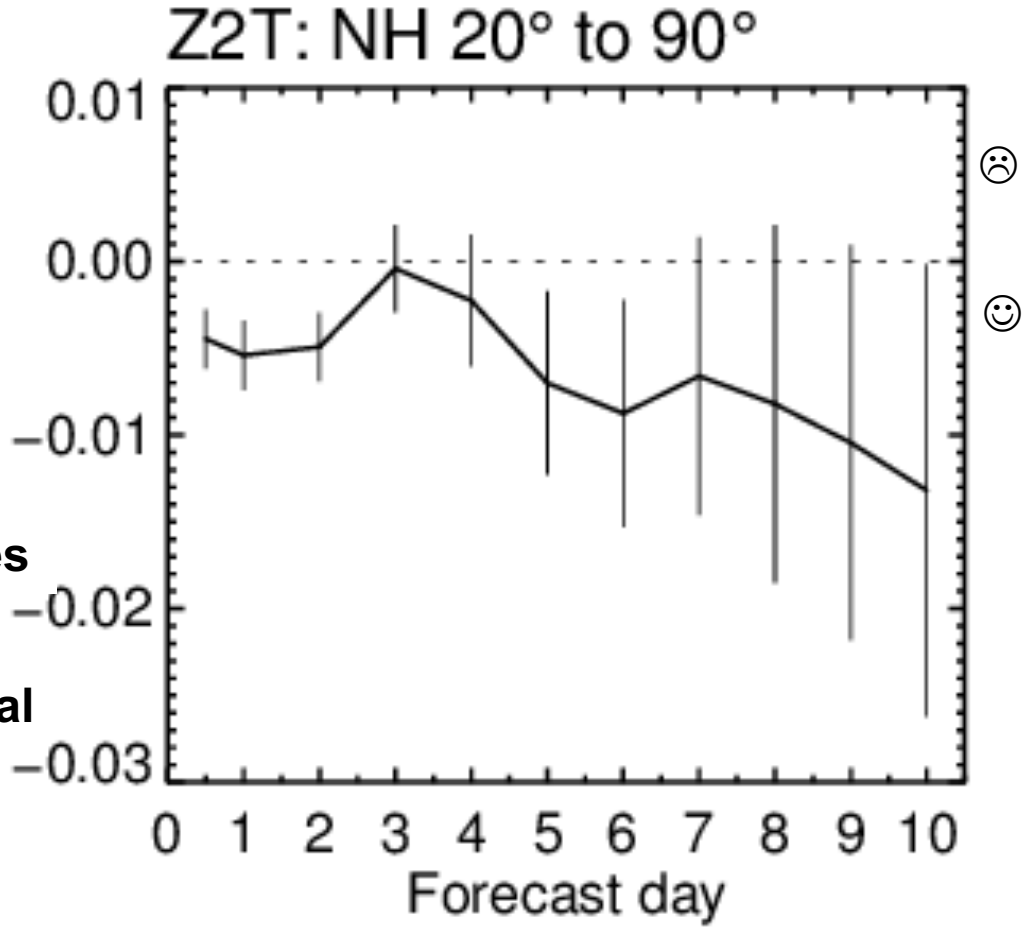
- OSEs in gobal (weakly) coupled land-atmosphere assimilation system

→ T2m forecasts error reduction at medium range

→ Contribution & complementarities of each observation types to improve T2m forecasts at short and medium ranges

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

DJFMA 2014-2015



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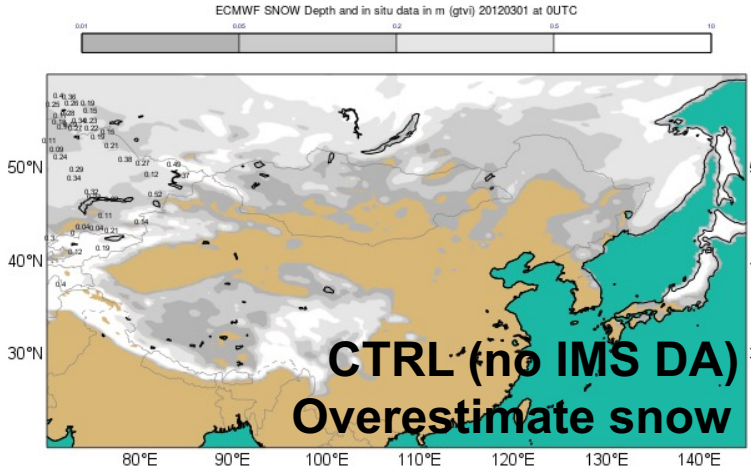
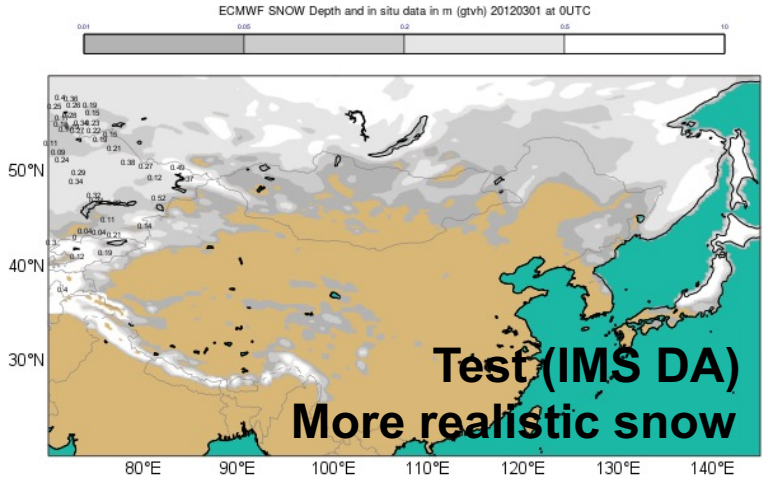
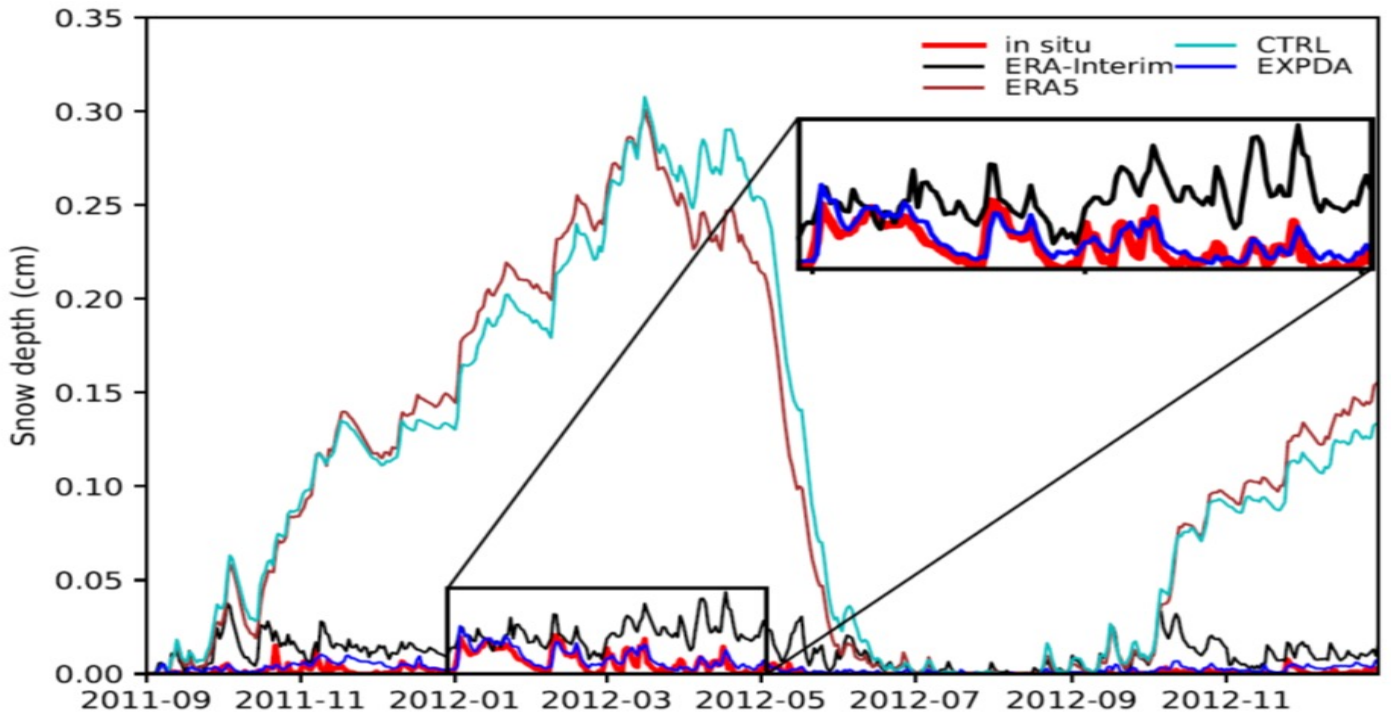
IMS snow cover coupled data assimilation impact over the Tibetan Plateau





IMS snow cover assimilation removes snow and improves snow depth



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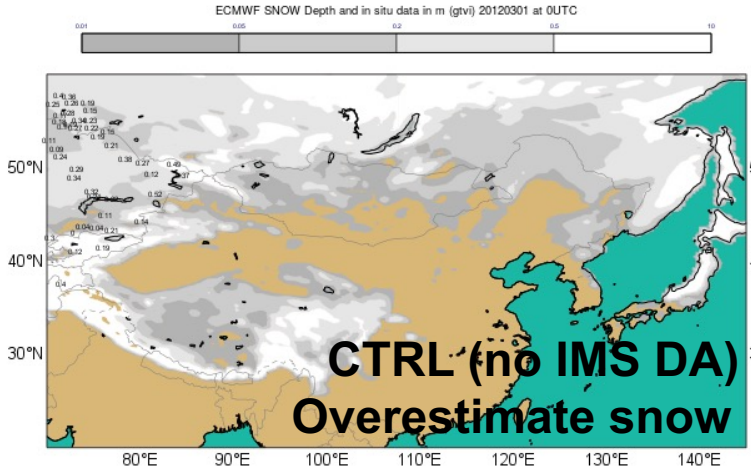
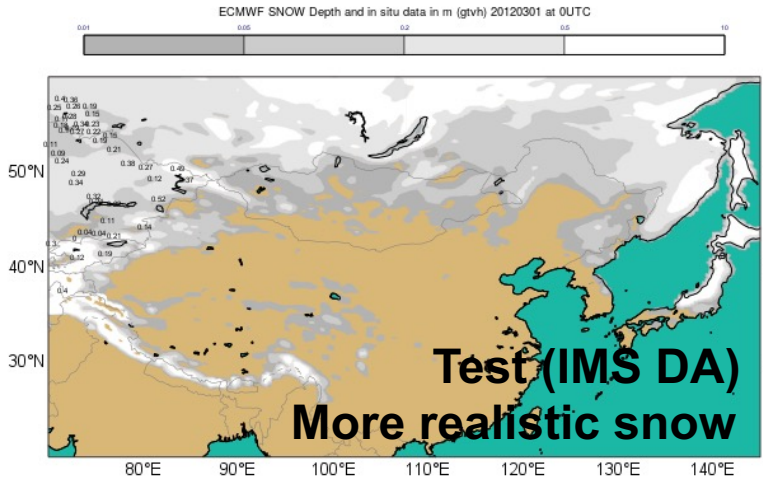
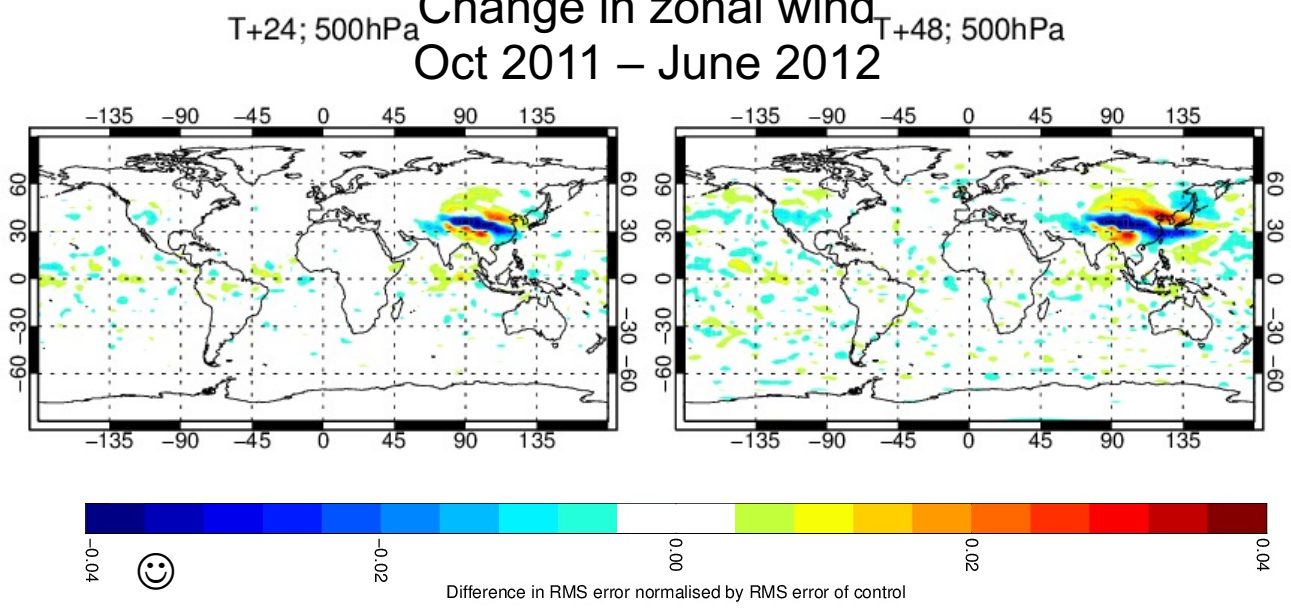


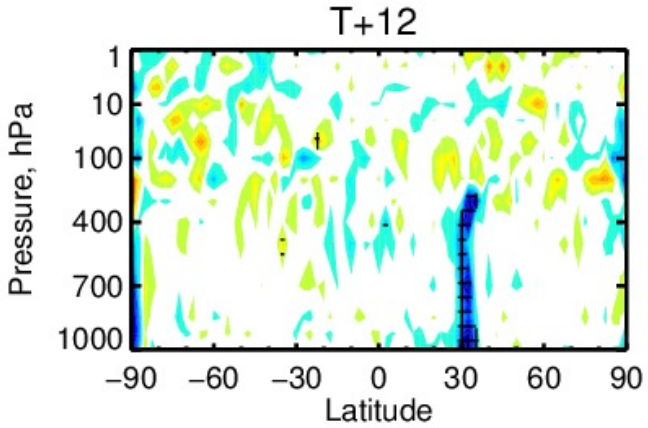


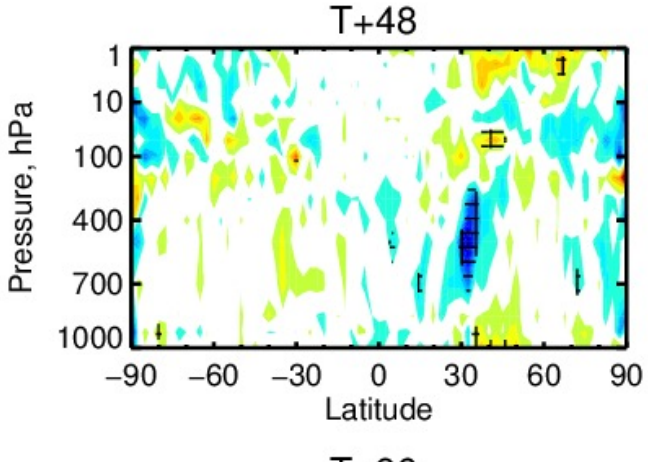
Impact on albedo and momentum
→ Modifies the jet circulation

Change in zonal wind
Oct 2011 – June 2012



Change in humidity FC error
Oct 2011 – June 2012





Soil moisture satellite observations used operationally

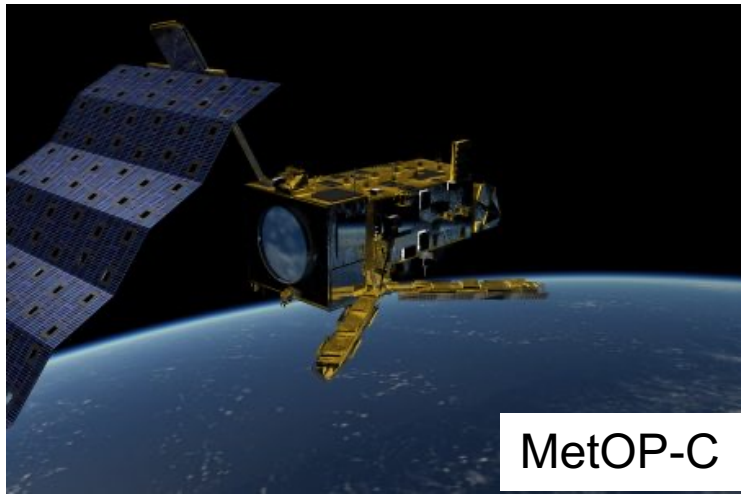
Active microwave data:

ASCAT: Advanced Scatterometer

On MetOP-A (2006-), MetOP-B (2012-), MetOP-C (2018-)

C-band (5.6GHz) backscattering coefficient

EUMETSAT Operational mission



MetOP-C

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

Passive microwave data:

SMOS: Soil Moisture & Ocean Salinity (2009-)

L-band (1.4 GHz) Brightness Temperature

ESA Earth Explorer, dedicated soil moisture mission

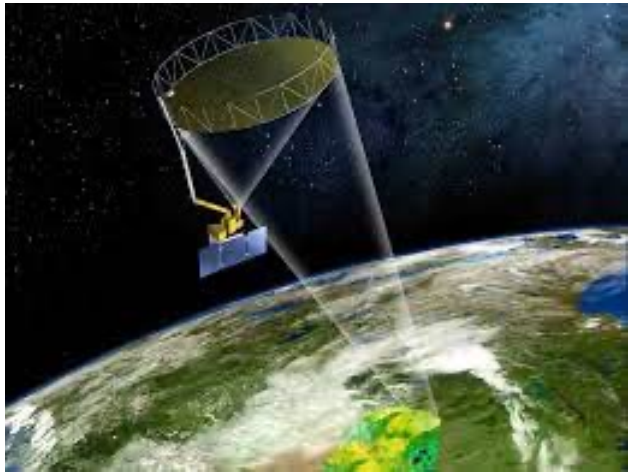
(Munoz-Sabater et al., GRSL, 2012)

SMOS

SMAP

L-band TB 2015-

NASA Dedicated soil moisture mission



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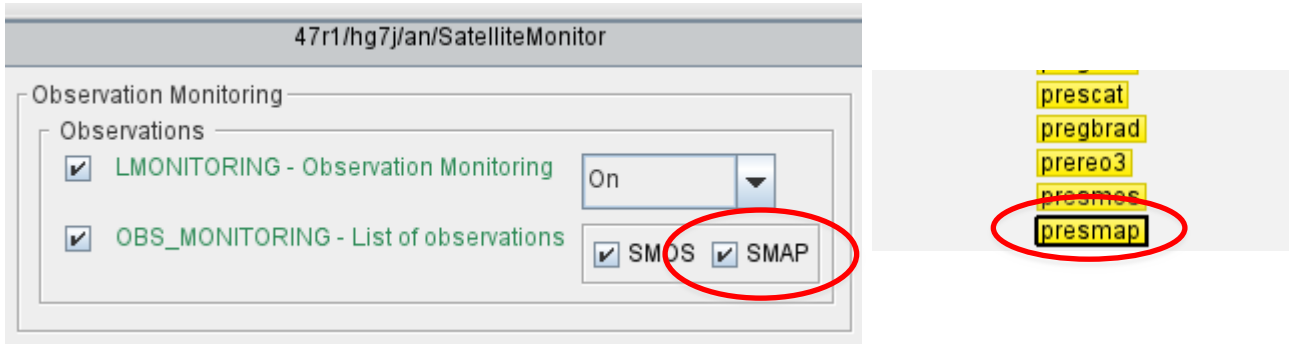
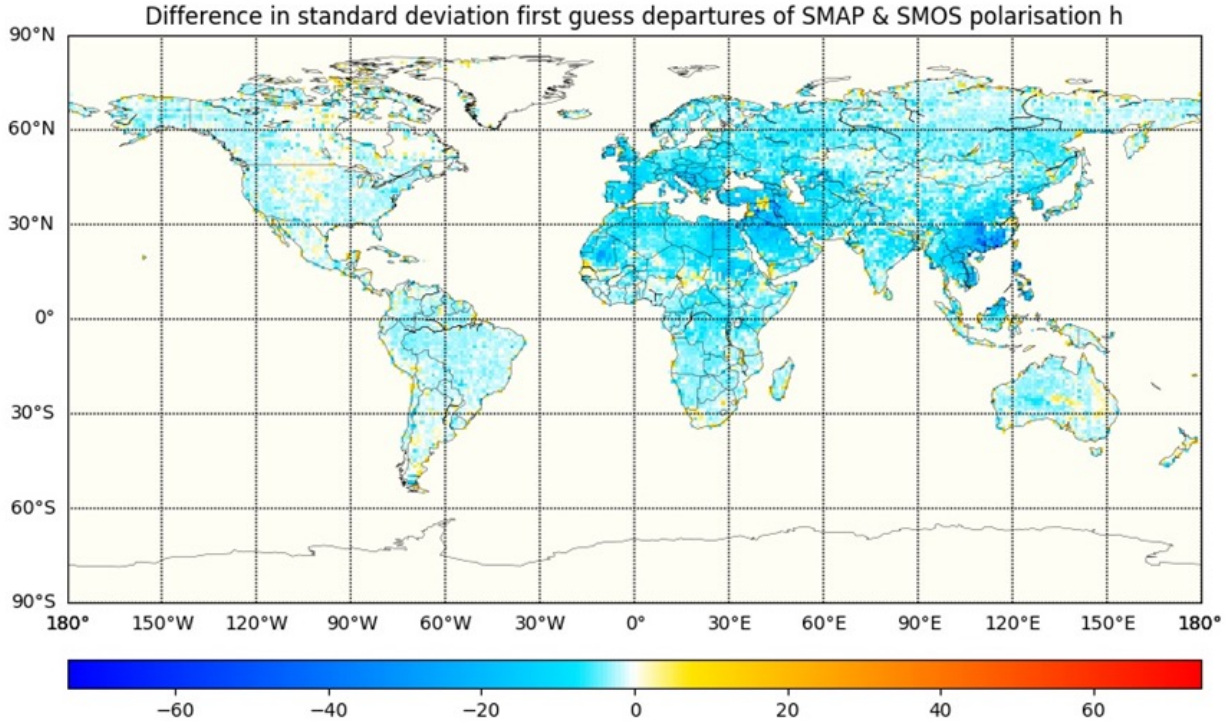
SMAP L-band observations

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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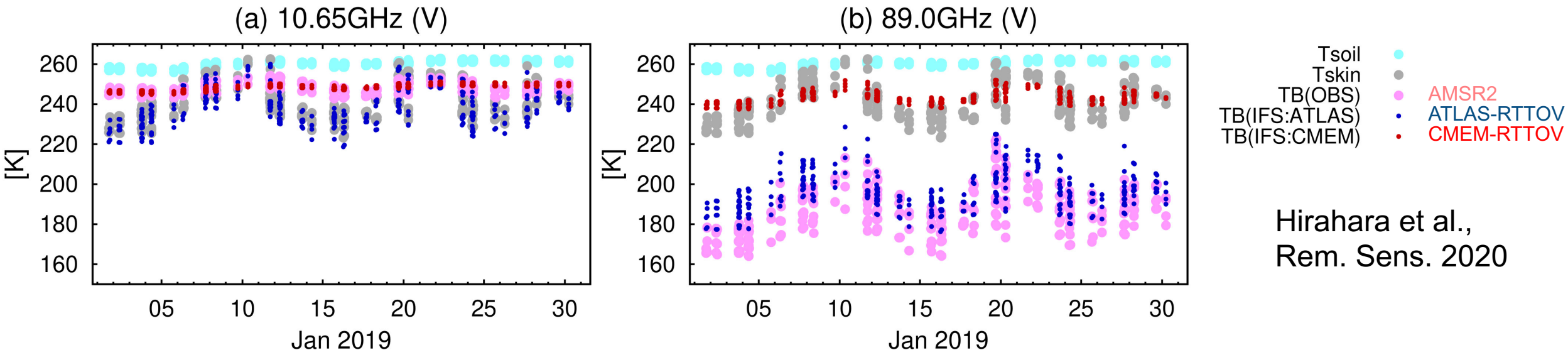
Pete Weston

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
  - Work on skin temperature DA over ocean and extend to land
  - Investigate multivariate soil and vegetation analysis (consistent water and CO2)
  - 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, consistent water-energy-carbon cycles assimilation (link Copernicus Services C3S, CMEMS, CEMS, CAMS)

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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/

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