«Современные проблемы физики»: atmospheric / ocean measurements, modelling & data assimilation for NWP / operational / climate applications

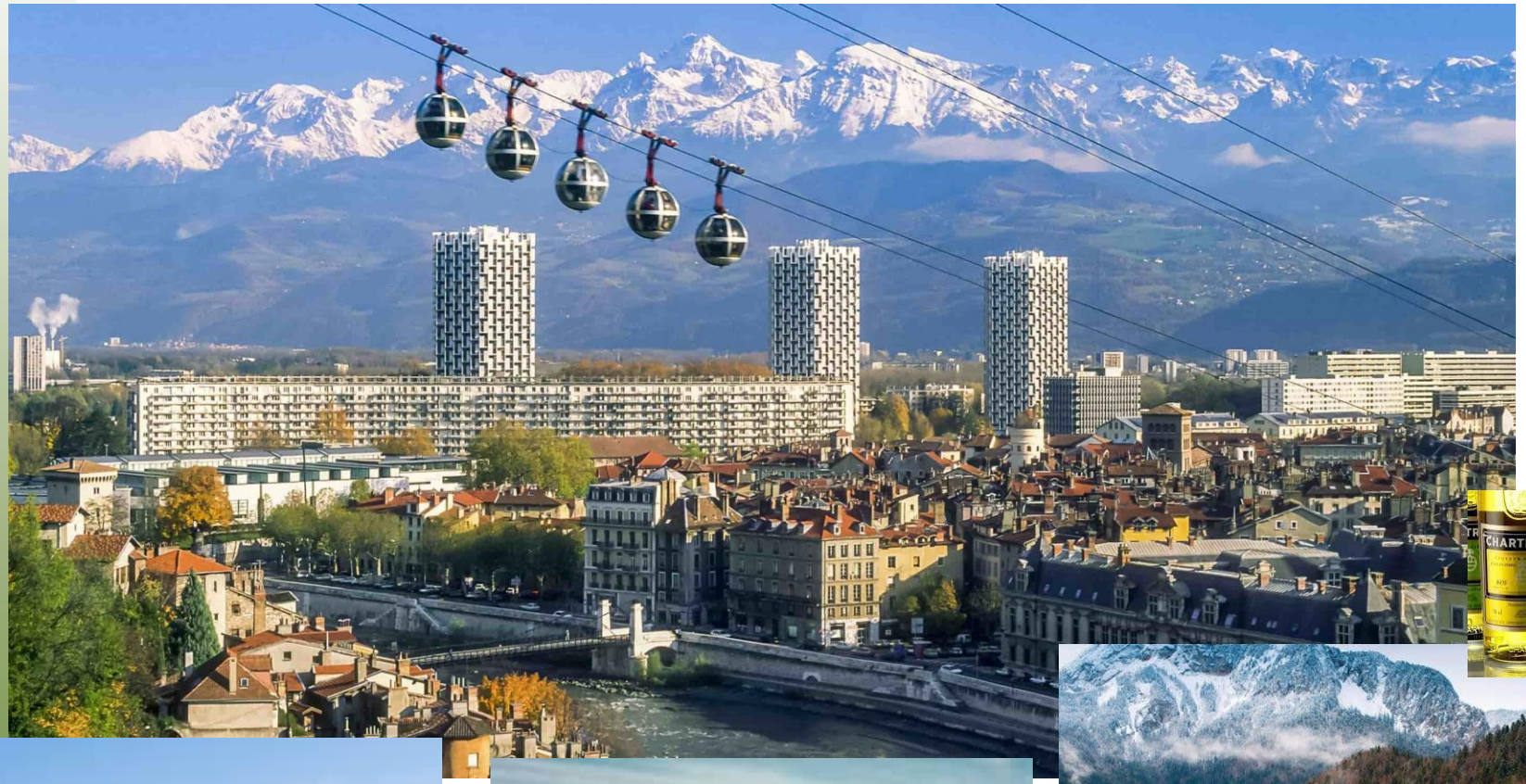
Sergey Skachko

distant.msu.ru, December 7th 2021

Résumé

- **Физфак МГУ, кафедра физики моря 1997-2003**
  - **динамические процессы в очаге цунами**
- Laboratoire des Écoulements Géophysiques et Industriels, CNRS, Grenoble, France, postdoc 2004-2006
  - ocean data assimilation
- Alfred Wegener Institut für Meereskunde, Bremerhaven, Deutschland, research scientist 2006-2008
  - ocean data assimilation
- Université du Québec à Montréal, Montréal (Québec), research scientist 2008-2011
  - coupled data assimilation
  - ocean / atmospheric modelling
- Koninklijk Belgisch Instituut voor Ruimte-Aeronomie / Institut royal de l'Aéronomie spatiale de Belgique, Brussel / Bruxelles, België / Belgique 2011-2016
  - CTM
  - stratospheric chemistry data assimilation
- Environnement et Changement climatique Canada / Environment and Climate Change Canada, Montréal, Québec, research scientist 2016-present time
  - coupled atmospheric-ocean-ice data assimilation

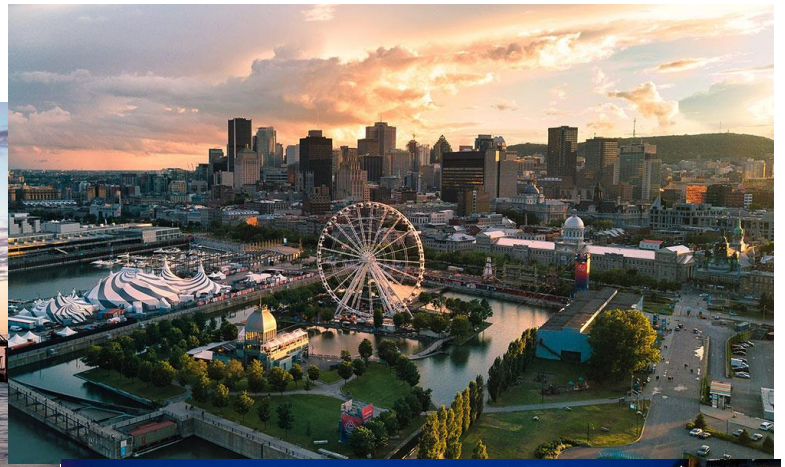
Laboratoire des Écoulements Géophysiques et Industriels, CNRS, Grenoble, France, postdoc 2004-2006



Alfred Wegener Institut für Meereskunde, Bremerhaven, Deutschland, research scientist 2006-2008

Université du Québec à Montréal, Montréal (Québec), research scientist 2008-2011






Environnement et Changement climatique C

Canada

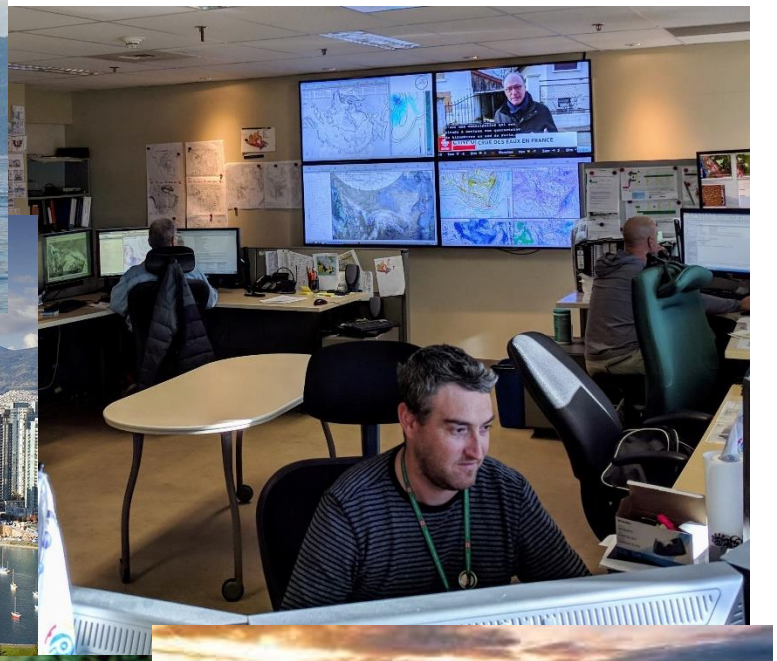
Koninklijk Belgisch Instituut voor Ruimte-Aeronomie / Institut royal de l'Aéronomie spatiale de Belgique, Brussel / Bruxelles, België / Belgique 2011-2016

6 – 7 déc

and
nge Cana

Environnement et Changement climatique Canada / Environment and Climate Change Canada, Montréal, Québec, research scientist 2016-present time








Environnement et Changement climatique Canada

Environment and Climate Change Canada

Canada

Outline

- **Intro**
- Observation systems
- Modelling
- Data assimilation methods
- NWP / operational / climate applications
- Skills

Intro: области интересов

- hydrology
- ocean ecosystem numerical modelling
- atmospheric chemistry
- waves
- renewable energy
- (coupled) ocean-atmosphere-ice systems for NWP and climate applications

Intro: перспективы карьеры

- research scientist:
  - applied research (government, NWP centres / operations)
  - fundamental research (universities), professorship
  - teaching
- scientific engineer
- scientific programmer
- R&D, operations
- management

Outline

- Intro
- **Observation systems**
- Modelling
- Data assimilation methods
- NWP / operational / climate applications
- Skills

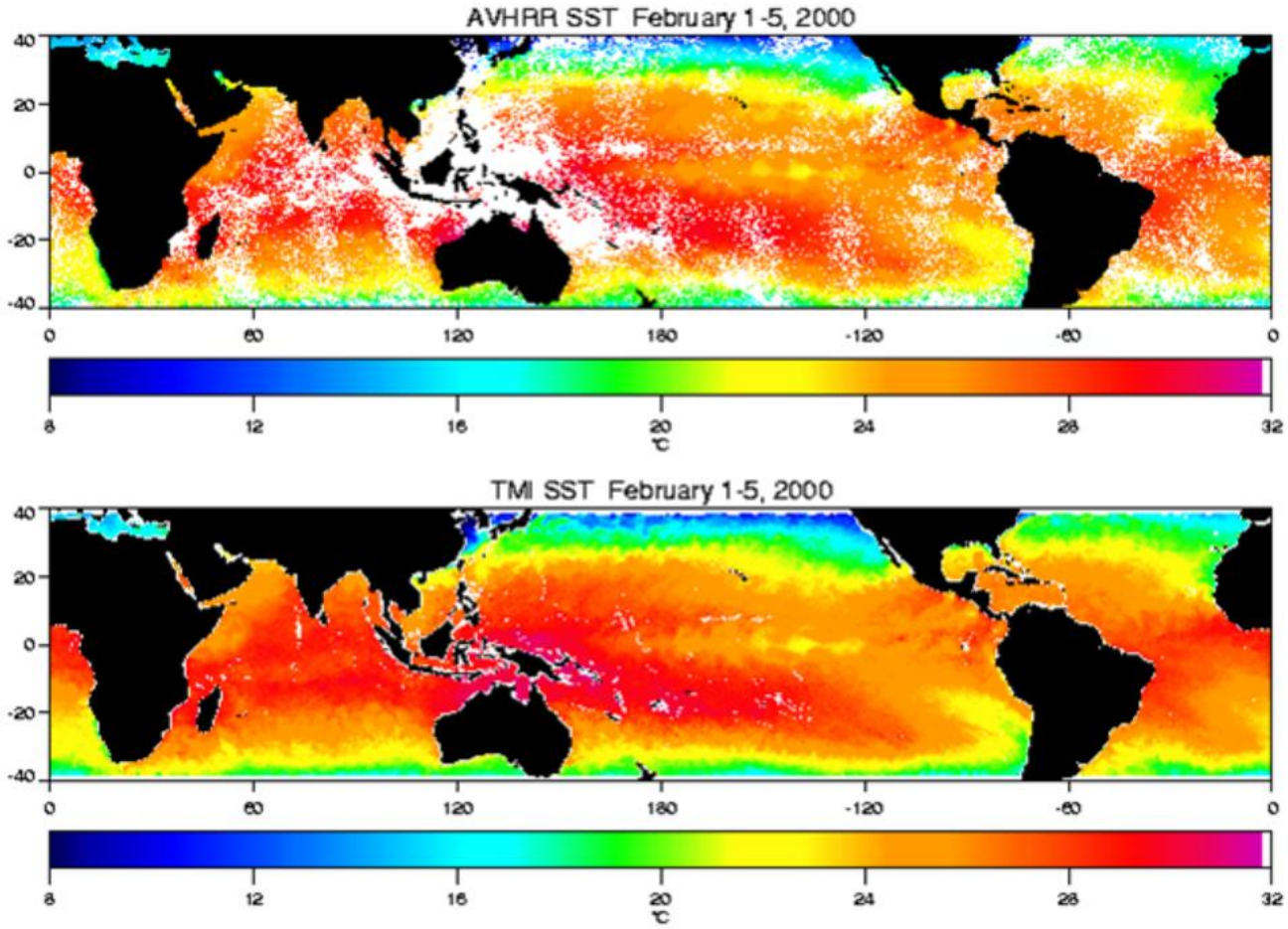
Monitoring the oceans

ocean measurements:

- insitu (T, S, p, bio & geophys.)
  - drifters
  - gliders
  - ships / buoys
  - bottom gages
  - sea mammals
- satellite
  - altimetry & geoid
  - (ocean) surface
  - biology / chemistry

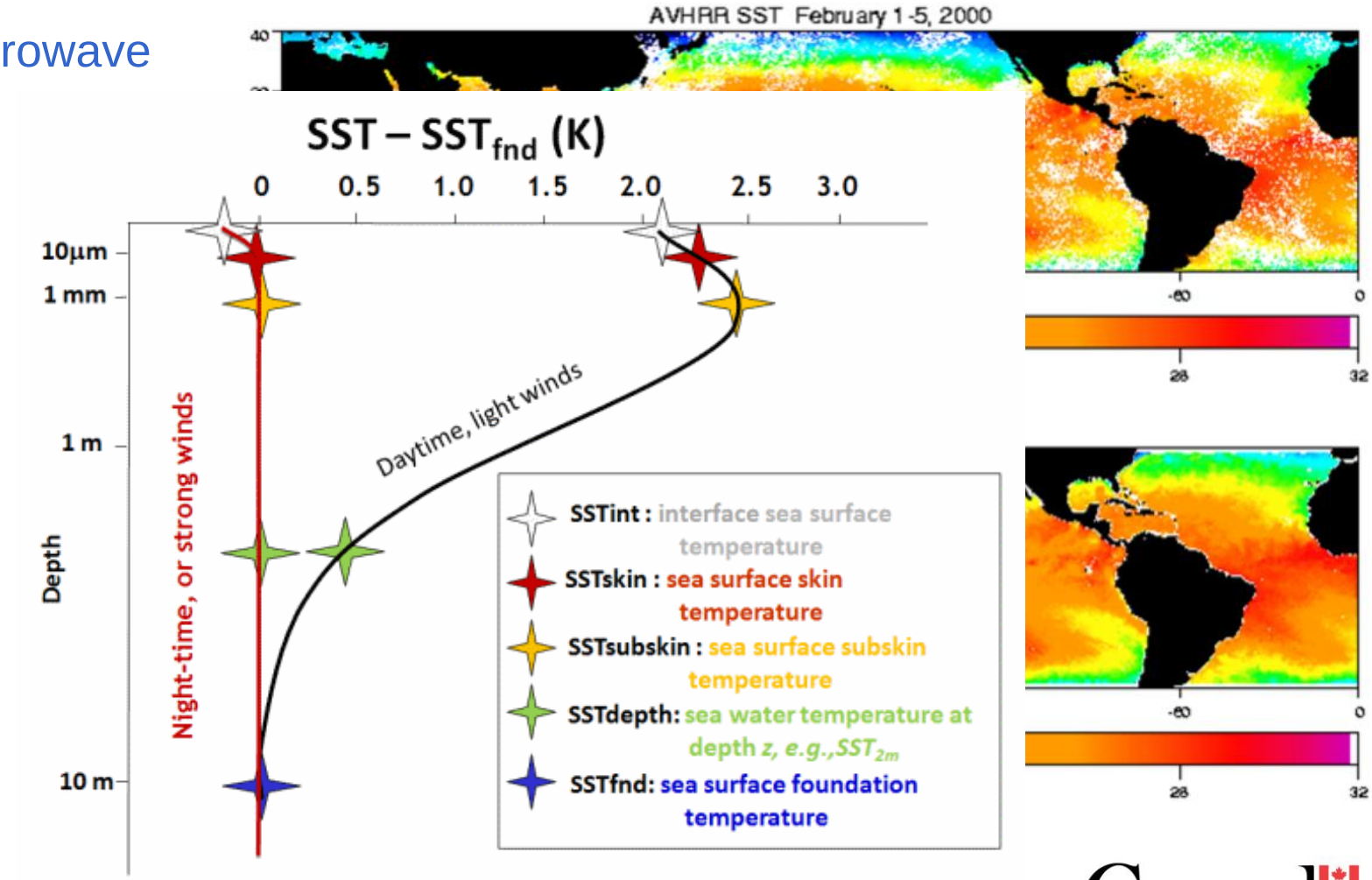
Satellite measurements

- Infrared
- Microwave

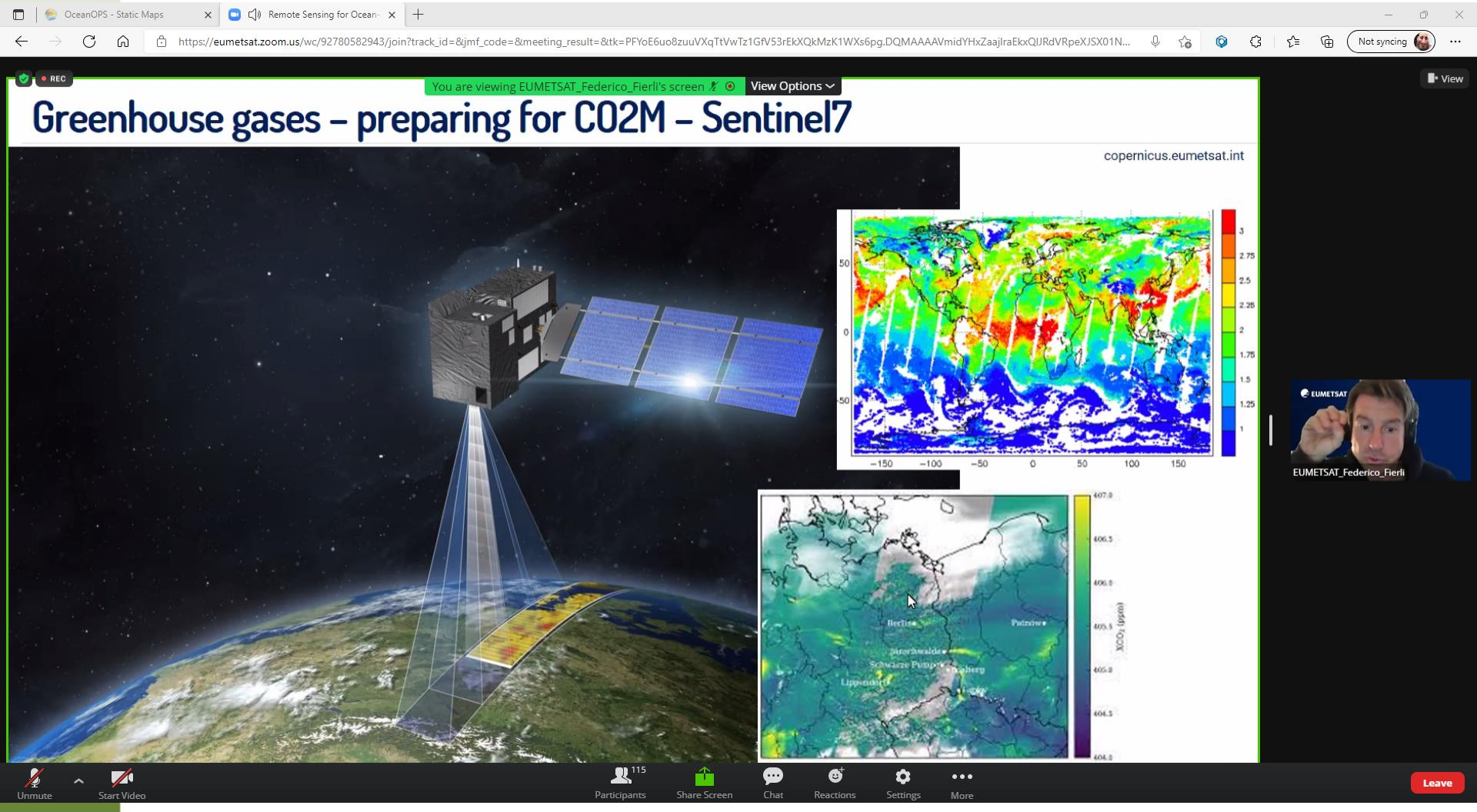


Satellite measurements

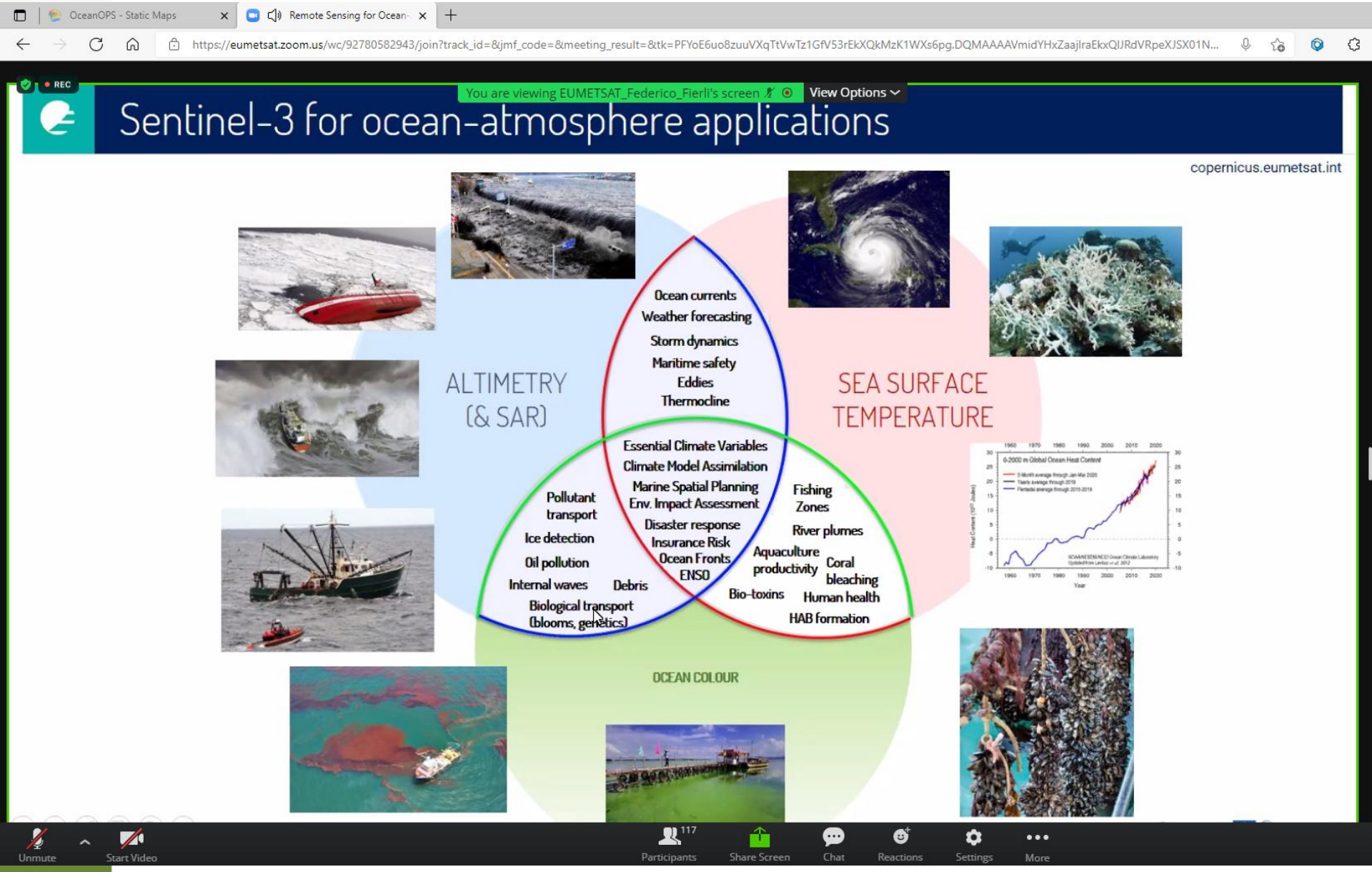
- Infrared
- Microwave



Monitoring the oceans: SENTINELLE

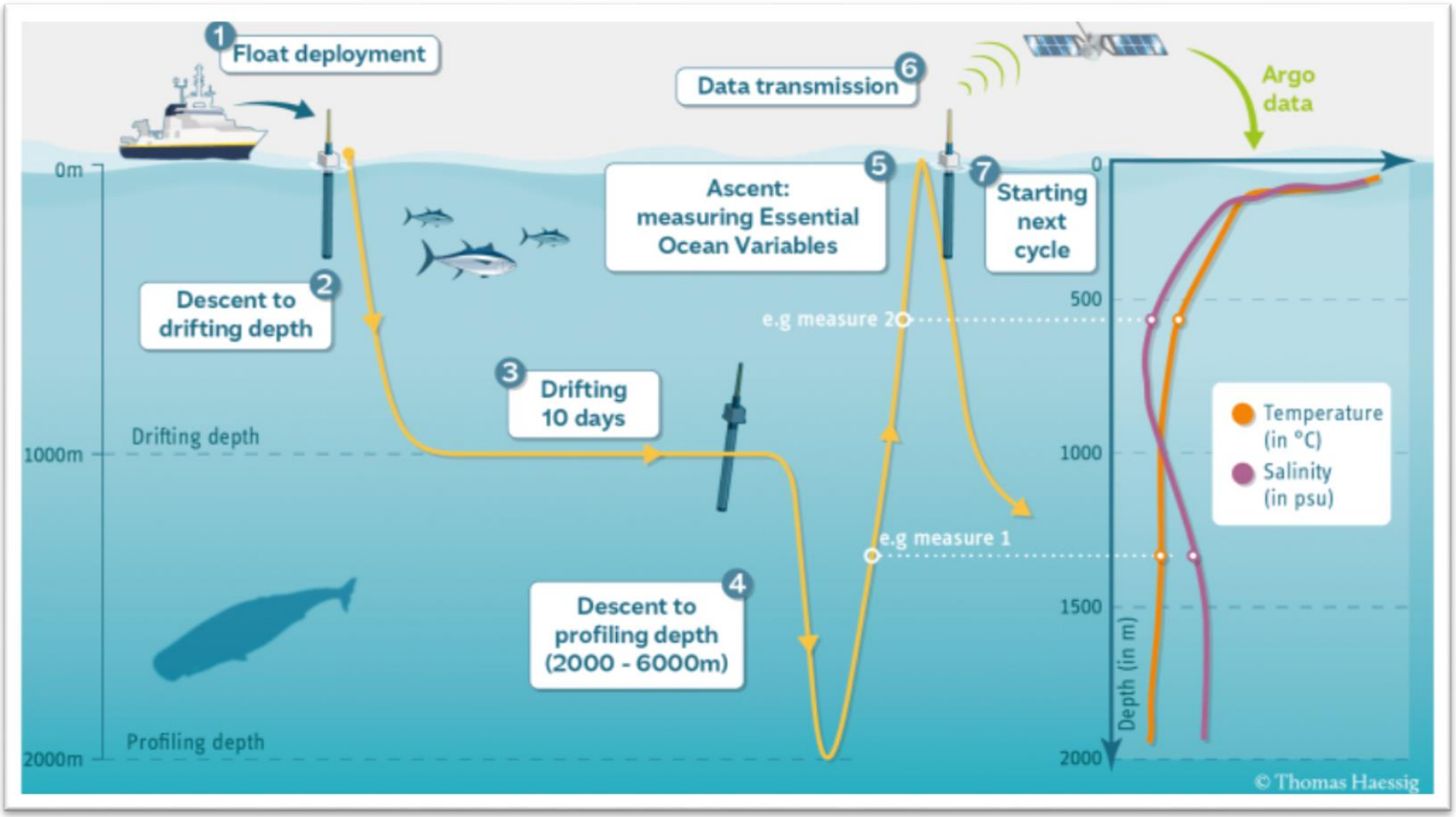


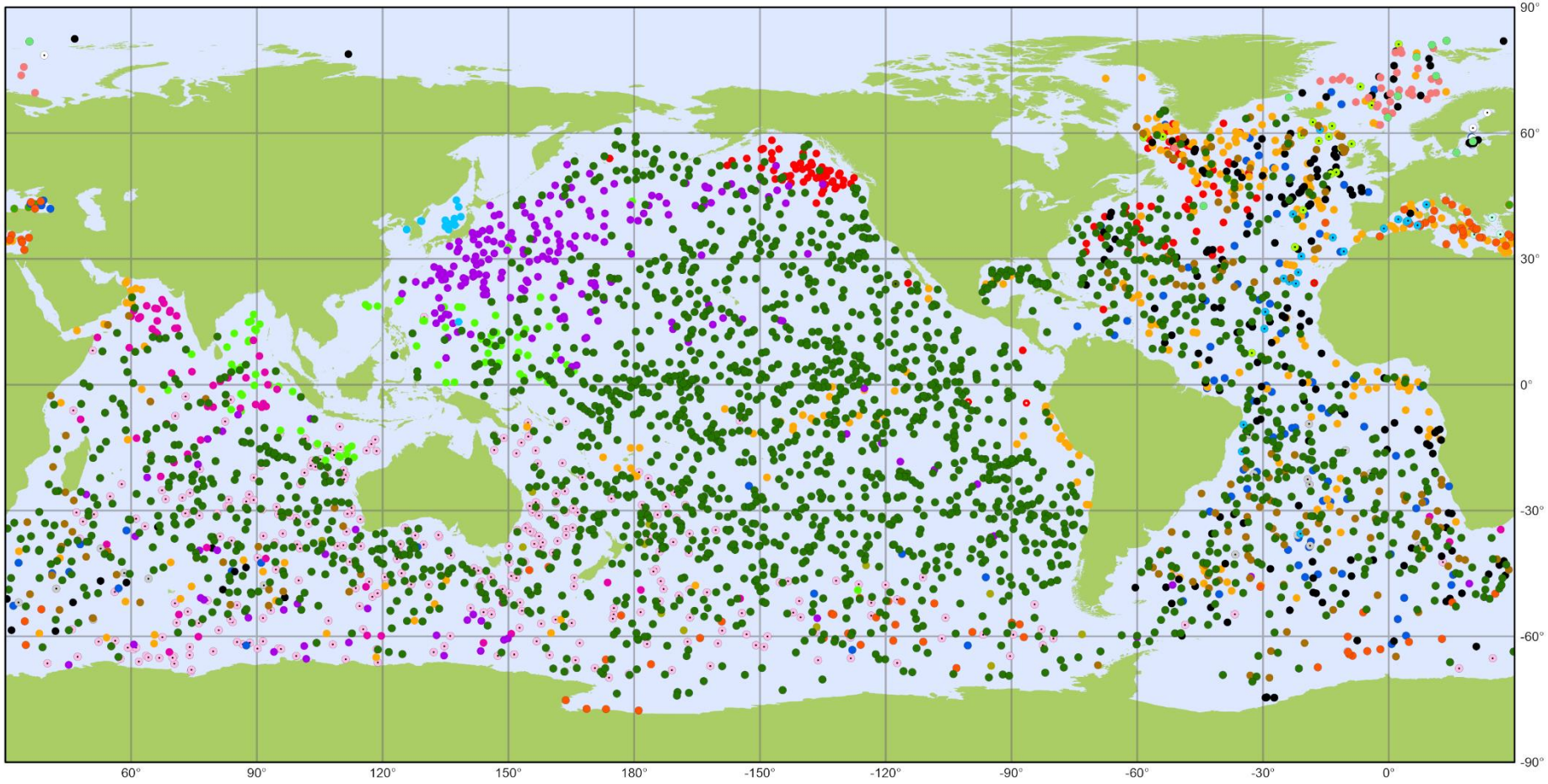
Monitoring the oceans: SENTINELLE



Argo international program

- collects information from inside the ocean
- using a fleet of robotic instruments:
  - drift with the ocean currents
  - move up and down between the surface and a mid-water level





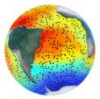
Argo

National contributions - 3870 operational floats

Latest location of operational floats (data distributed within the last 30 days)

October 2021

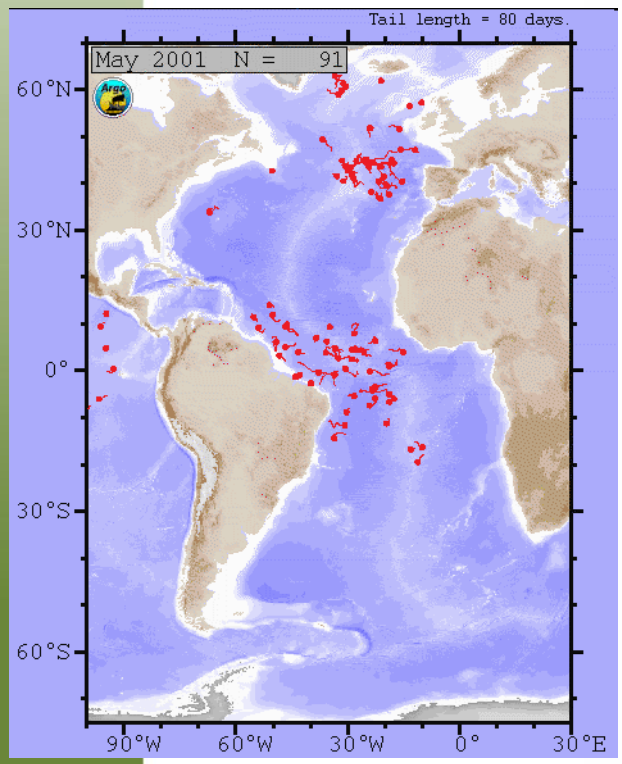
AUSTRALIA (307)	FINLAND (5)	IRELAND (19)	NETHERLANDS (19)	KOREA, REPUBLIC OF (13)
BULGARIA (6)	FRANCE (272)	ITALY (82)	NEW ZEALAND (14)	SPAIN (21)
CANADA (113)	GERMANY (201)	JAPAN (228)	NORWAY (36)	UK (150)
CHINA (77)	GREECE (3)	MEXICO (1)	PERU (2)	USA (2117)
EUROPE (109)	INDIA (63)	MOROCCO (1)	POLAND (11)	

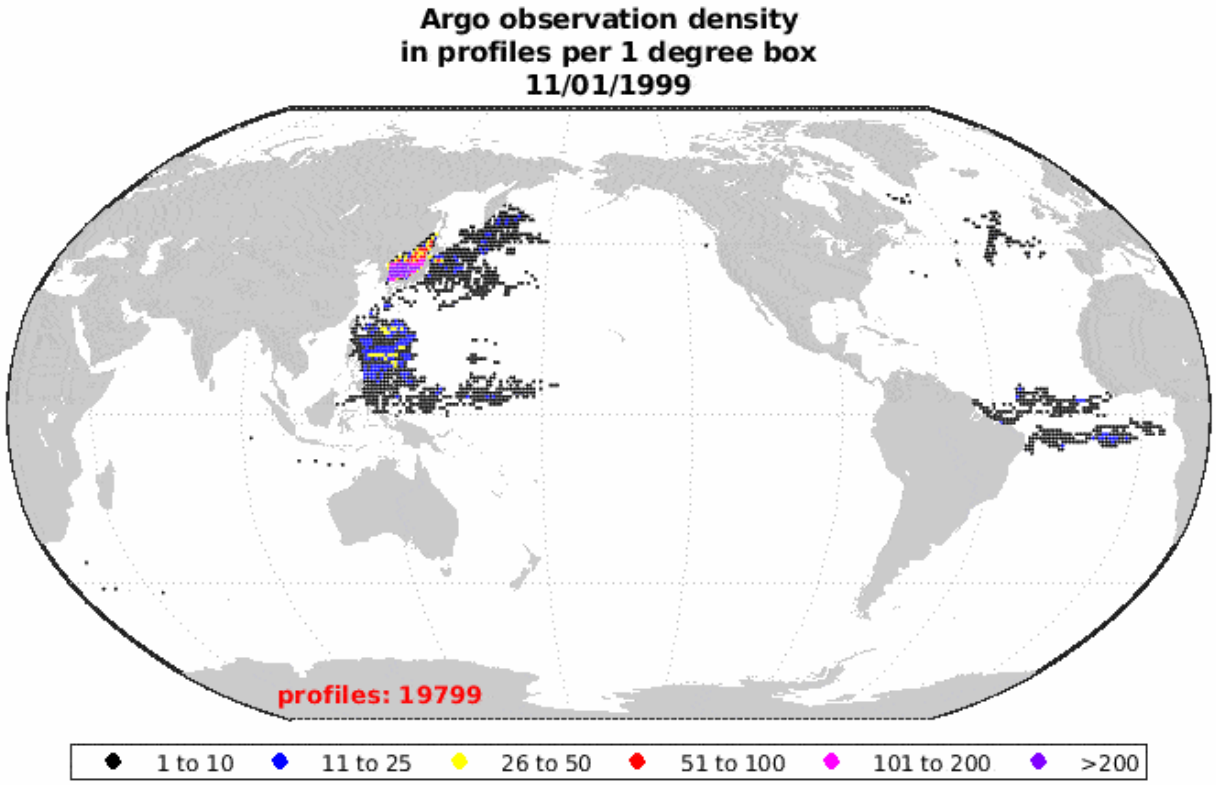


Generated by ocean-ops.org, 2021-11-01
Projection: Plate Carree (-150.0000)

Argo international program

Evolution of the program: Atlantic ocean (left), globally (right)





Monitoring the oceans: Copernicus Marine Service

Monitoring the planet: Copernicus Climate

Climate Change

Climate data records of Essential Climate Variables (ECVs)

C3S supports 22 ECV services grouped in 5 thematic areas:

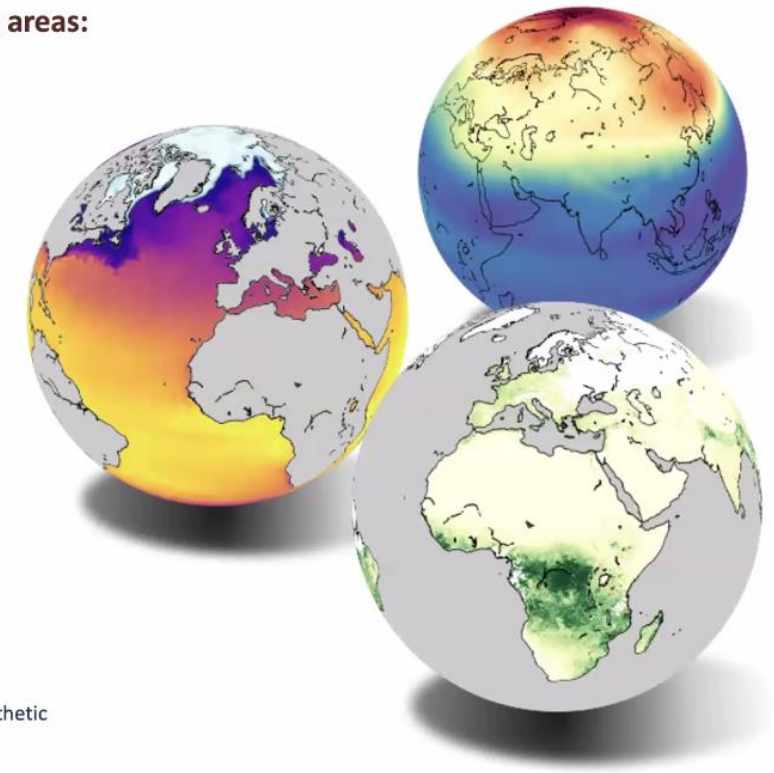
Atmospheric physics
- Precipitation
- Surface radiation budget
- Water vapour
- Cloud properties
- Earth radiation budget

Atmospheric composition
- Carbon dioxide
- Methane
- Ozone
- Aerosol

Ocean
- Sea surface temperature
- Sea level
- Sea ice
- Ocean colour

Land hydrology & cryosphere
- Lakes
- Glaciers
- Ice sheets & ice shelves
- Soil moisture

Land biosphere
- Albedo
- Land cover
- Fraction of absorbed photosynthetic
- Leaf area index
- Fire



ECV products that are

- State-of-the-art
  - *Coordination with ESA CCI, EUMETSAT/SAFs & other Copernicus Services*
- Long-term, consistent , complete (CDR)
  - **Single/Multi sensor approach**
- Regularly extended in time (ICDR)
  - **Frequent updates of data records**
- Gridded, aggregated
  - **Meeting user requirements**
- *Accessible & Traceable*
  - *Access through the Climate Data Store*
  - *Documentation*
  - *Quality Assurance*
  - *User support*

Scientific requirements are based on Global Climate Observing System (GCOS) framework.

ECMWF Copernicus Europe's eyes on Earth European Commission

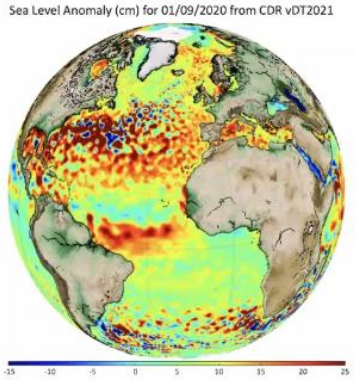
Monitoring the planet: Copernicus Sea Level & Ocean Color

Climate Change

C3S Ocean ECVs: Sea Level & Ocean Colour

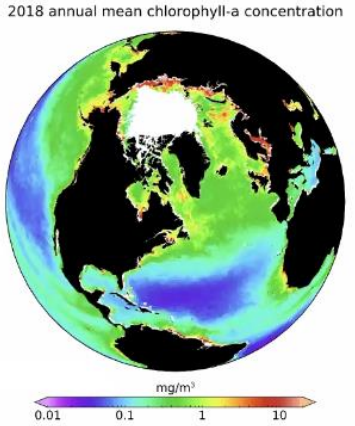
Sea Level

- Daily global estimates of **sea level anomaly**, **absolute dynamic topography**, and **geostrophic velocities**
- Available from Jan 1993 onward
- Based on altimetry measurements from a 2-satellite constellation:
  - **Reference mission** (T/P, Jason-1, Jason-2, Jason-3)
  - **Complementary mission** (ERS-1/2, Envisat, SARAL/Altika, Sentinel-3A)
- Products optimised for climate monitoring → focus on homogeneity and stability
- Resolution: 0.25° lat-lon
- Data updated 3x/year with 5-month latency behind real time
- Latest version: **vDT2021** (released in Oct 2021)



Ocean Colour

- Daily global estimates of ocean surface **chlorophyll-a concentration** and **remote sensing reflectance**
- Based on multiple sensors: SeaWiFS, MERIS, MODIS Aqua, VIIRS, and (from v5.0 onward) OLCI
- Processing chain software developed as part of **ESA OC CCI**
- Resolution: 0.042° lat-lon (4 km at Equator)
- Quarterly updates with 9-12 month latency behind real time
- Latest version: **v5.0** (released in Nov 2020)



Copernicus Europe's eyes on Earth | European Commission

Monitoring the planet: Copernicus Sea Ice

Climate Change

C3S Ocean ECVs: Sea Ice

Sea Ice Thickness

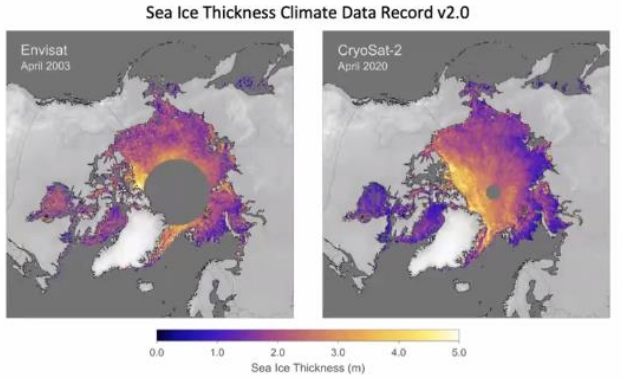
- ❑ Monthly product for the Northern Hemisphere
- ❑ Based on radar altimetry measurements from **Envisat** (10/2002 – 10/2020) and **CryoSat-2** (11/2010 – present)
- ❑ Resolution: 25 km
- ❑ Daily data available with 16-day latency behind real time
- ❑ Latest version: **v2.0** (released in Oct 2021)

Sea Ice Type

- ❑ Daily classification of sea ice as **first-year ice** or **multiyear ice**
- ❑ Based on PMW measurements from SMMR-SSM/I-SSMIS
- ❑ Available for N. Hemisphere from October through April
- ❑ Resolution: 25 km
- ❑ Daily data available with 16-day latency behind real time
- ❑ Latest version: **v2.0** (released in Sept 2021)

Sea Ice Edge

- ❑ Daily classification of sea surface as **open water**, **open ice**, or **closed ice**
- ❑ Based on PMW measurements from SMMR-SSM/I-SSMIS
- ❑ Available for N. and S. Hemispheres
- ❑ Resolution: 12.5 km
- ❑ Daily data available with 16-day latency behind real time
- ❑ Latest version: **v2.0** (released in Sept 2021)



Copernicus Europe's eyes on Earth

European Commission

Forschungseisbrecher Polarstern

À PROPOS D'AMUNDSEN SCIENCE

Amundsen Science est l'organisme à but non-lucratif responsable du mandat scientifique du brise-glace de recherche NGCC *Amundsen*. Fonctionnant en grande partie grâce au financement octroyé par la Fondation canadienne pour l'innovation à l'Université Laval, Amundsen Science gère et entretient le parc d'équipements scientifiques du navire, coordonne les expéditions scientifiques en collaboration avec la garde côtière canadienne et fournit un support technique aux usagers du programme scientifique lorsque le navire est en mer.

Outline

- Intro
- Observation systems
- **Modelling**
- Data assimilation methods
- NWP / operational / climate applications
- Skills

High Performance Computer (HPC)

HPC Upgrade #1: Supercomputers

XC40	XC50
2 x 18 core, 2.1 Ghz	2 x 20 core, 2.4Ghz
Broadwell	Skylake
792 compute nodes	1,266 compute nodes
28,512 compute cores	50,640 compute cores
128 GB 4 channel DDR4-2400	192 GB 6 channel DDR4-2666

- Essentially, a bigger version of a machine we already know well.
- Increase of ~1.6x increase in number of nodes, and ~1.8x increase in total number of compute cores.

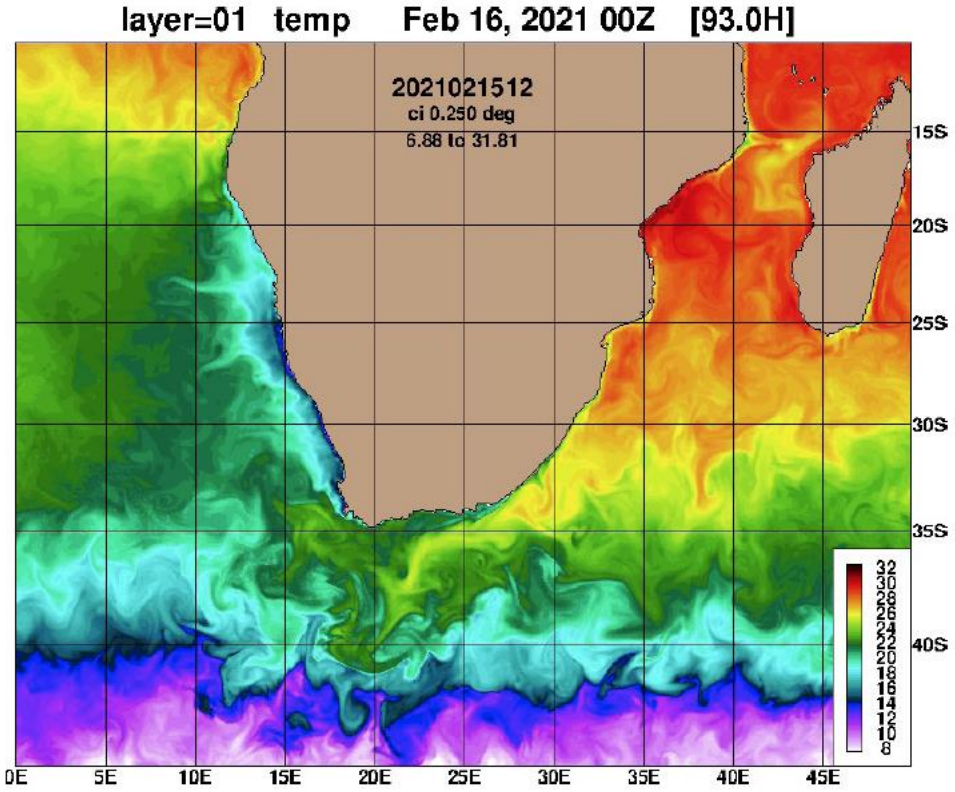
HPC Upgrade #1: PPP Clusters

CS-400	CS-500
2 x 22 core, 2.1 Ghz	2 x 20 core, 2.4Ghz
Broadwell	Skylake
158 compute nodes	248 compute nodes
6,952 compute cores	9,920 compute cores
225 GB 4 channel DDR4-2400	192 GB 6 channel DDR4-2666

- Compute nodes have same processor as the XC50.
- Increase of ~1.6x increase in number of nodes, and ~1.4x increase in total number of compute cores.

Ocean / atmospheric modelling

- global
- regional
- nested

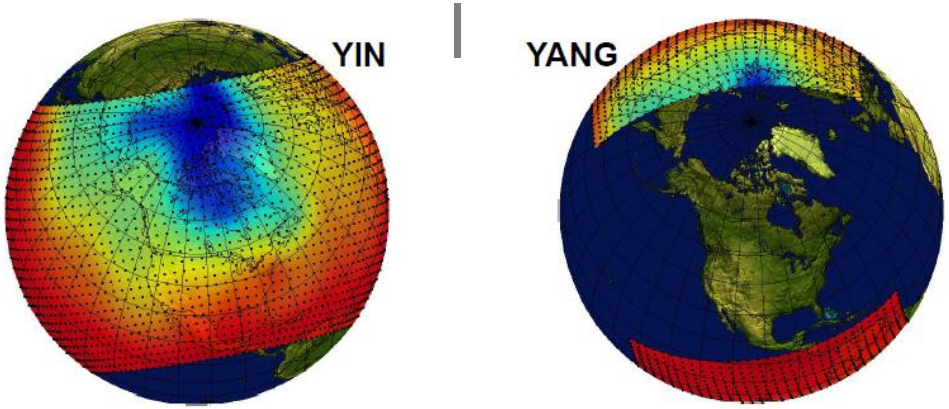


GOFS forecast sea surface temperature, Day 7-1/2
(Source: U.S. Naval Research Laboratory)

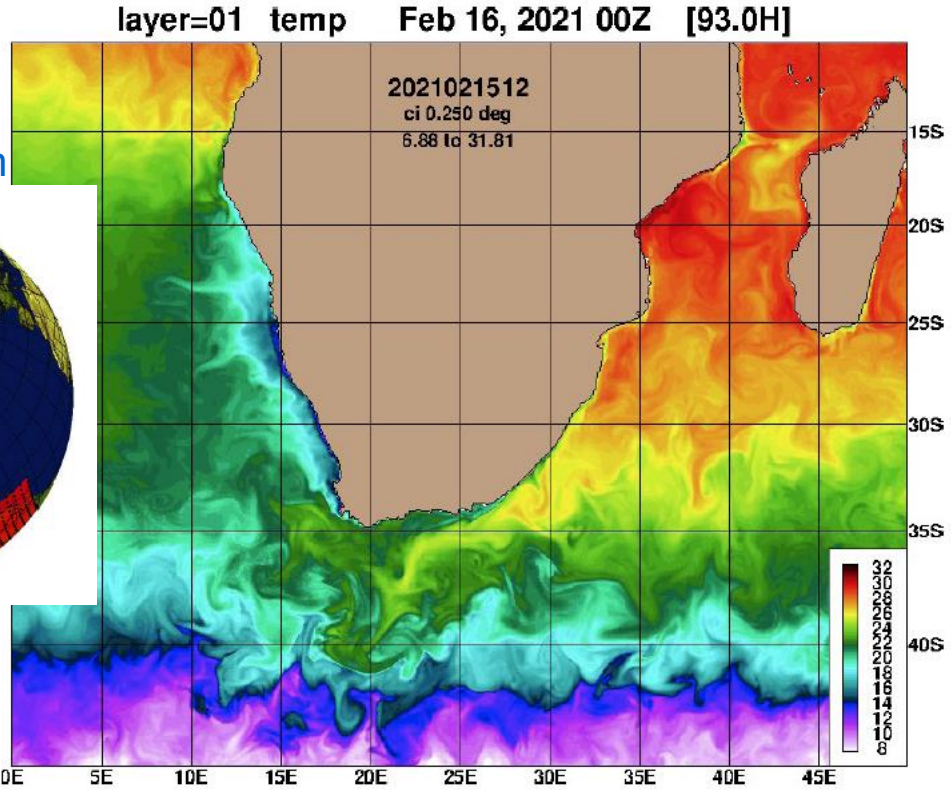
Ocean / atmospheric modelling

- global

Global, Δx =25km



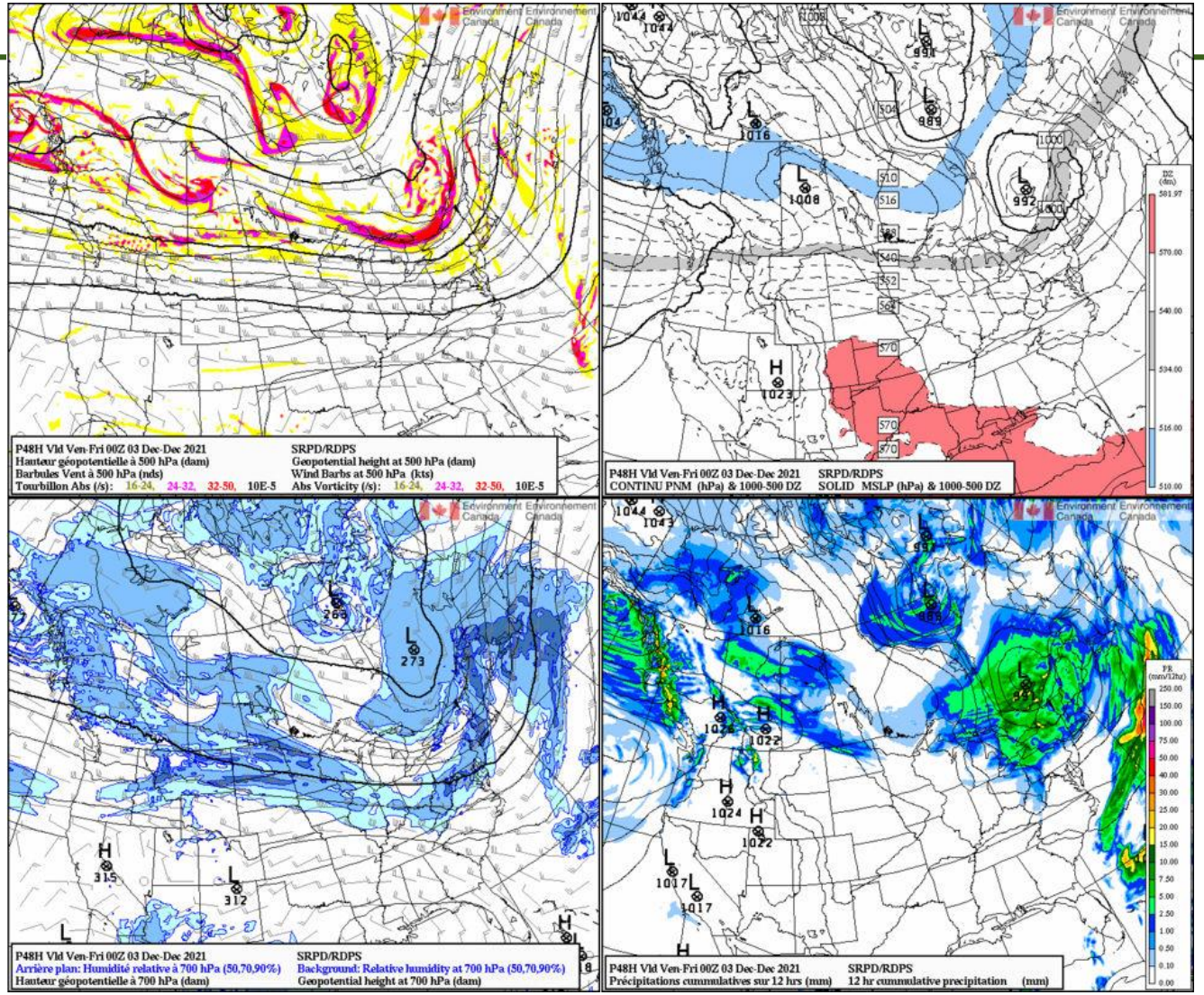
Canadian atmospheric model GEM



GOFS forecast sea surface temperature, Day 7-1/2
(Source: U.S. Naval Research Laboratory)

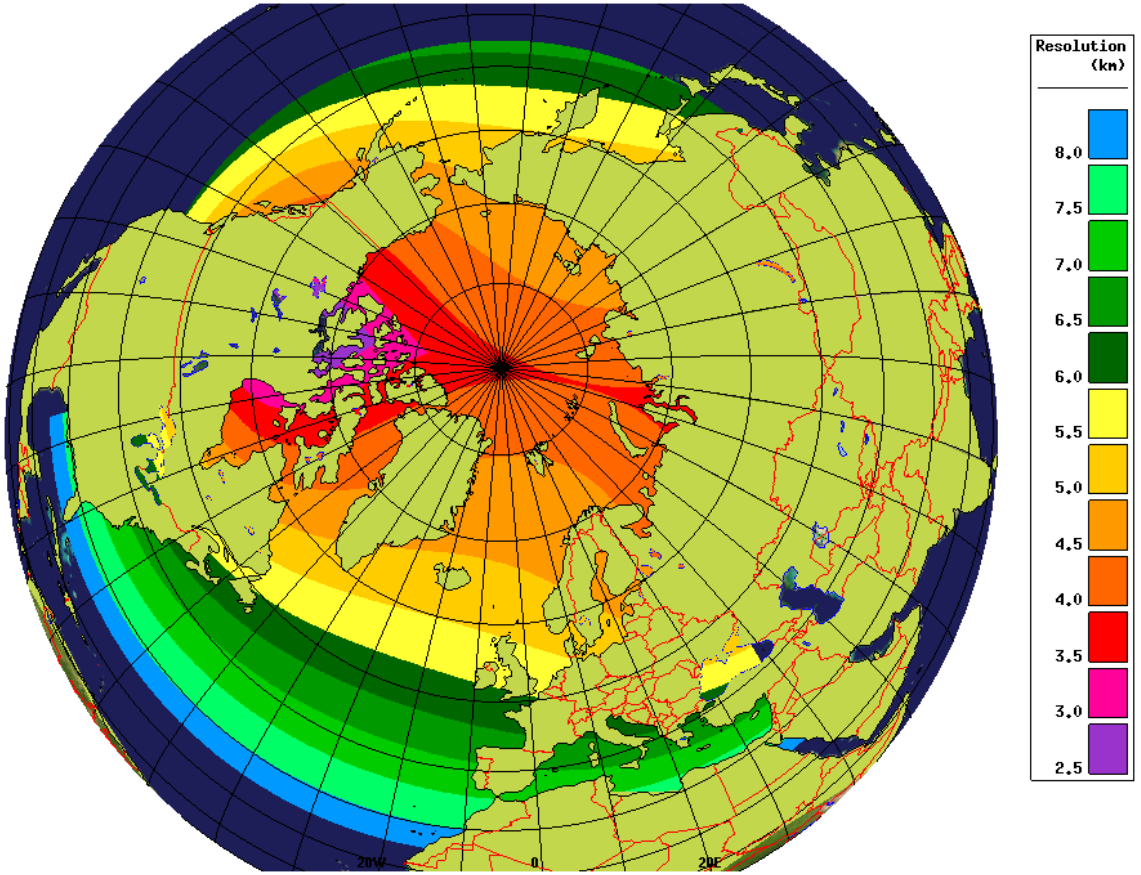
Ocean / atmospheric modelling

- global
- regional
- nested



Canadian Ice-Ocean Prediction System

- global
- regional
- nested



The coverage of the Canadian ice-ocean prediction system showing the model grid resolution (km). The domain extends from 26° N in the Atlantic Ocean over the Arctic Ocean to 44° N in the Pacific Ocean. (source: Smith et al 2021)

AGRIF nested grids

- nested

https://www.croco-ocean.org/download/roms_agrif-project/

CROCO
Coastal and Regional Ocean COmmunity model

HOME DOWNLOAD DOCUMENTATION CONTACTS HOW TO CITE ?

SUMMARY

Source code

Roms_Agrif v3.1.1 : Latest stable version, 07 July 2014

Roms_Agrif v3.1 : 03 February 2014

Roms_Agrif v3.0 :

Roms_Agrif v2.2 :

Roms_Agrif v2.1 :

Sources Change Log

2014

2012

2010

Roms tools

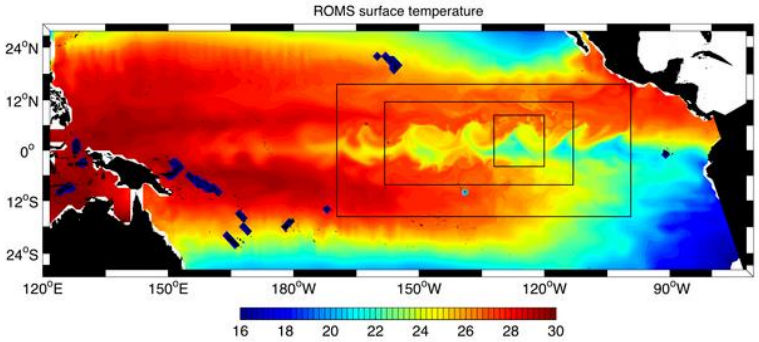
ROMSTOOLS V3.1.1 : Latest stable version, 07 July 2014.

ROMSTOOLS V3.1 : 03 February 2014.

ROMSTOOLS V3.0 : 21 December 2012.

ROMSTOOLS V2.2 : 16

ROMS_AGRIF PROJECT



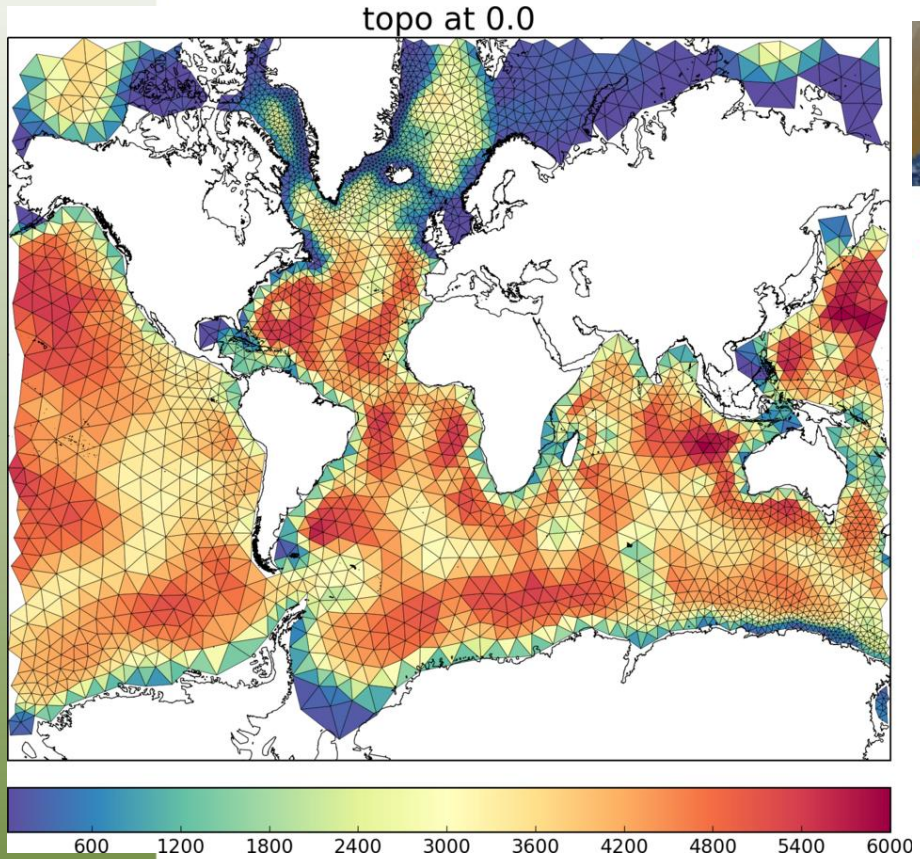
ROMS_AGRIF is based on the Regional Ocean Modeling System (ROMS) and has benefited from developments made by the ROMS community. If not done yet, we encourage you to also register at the official ROMS website.

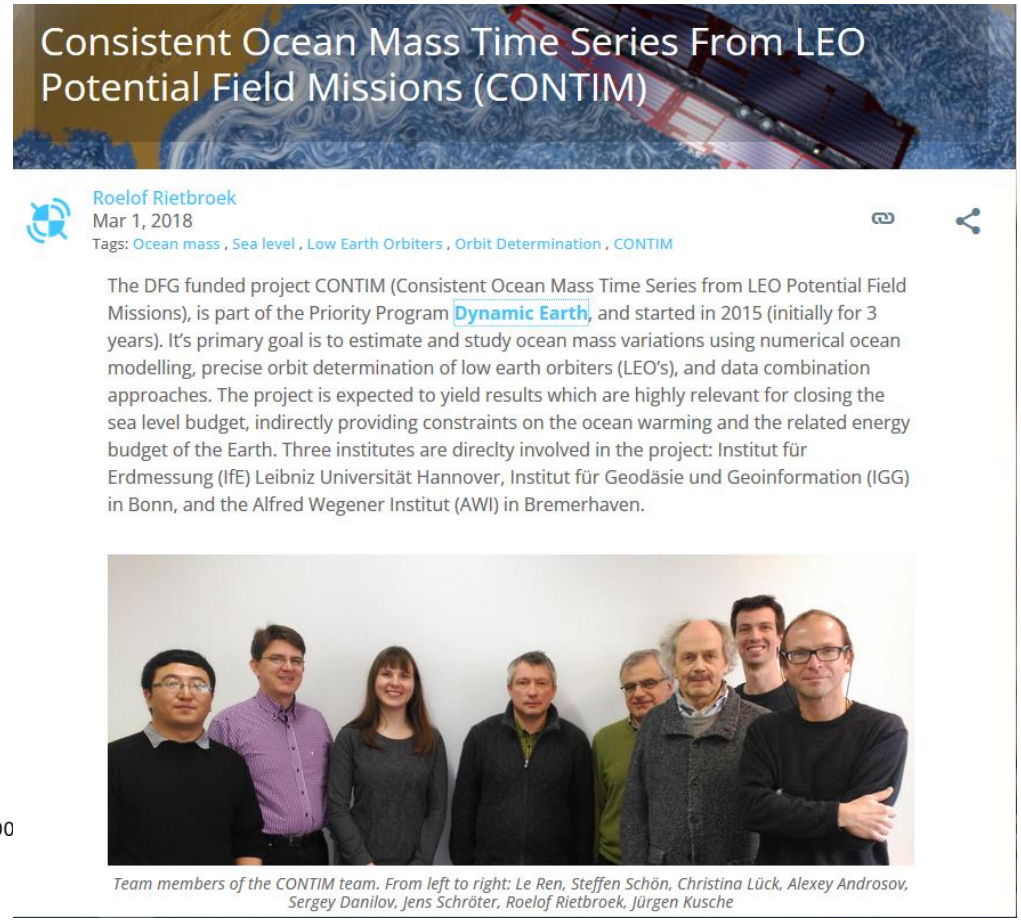
ROMSTOOLS is free software; you can redistribute it and/or modify it under the terms of the GNU General Public License as published by the Free Software Foundation; either version 2 of the License, or (at your option) any later version. ROMSTOOLS is distributed in the hope that it will be useful, but WITHOUT ANY WARRANTY; without even the implied warranty of MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE. See the GNU General Public License for more details. You should have received a copy of the GNU General Public License along with this program; if not, write to the Free Software Foundation, Inc., 59 Temple Place, Suite 330, Boston, MA 02111-1307 USA

ROMSTOOLS uses several Matlab Utilities, and Datasets available for download.

See Change Log section for Known problems and Fixes.

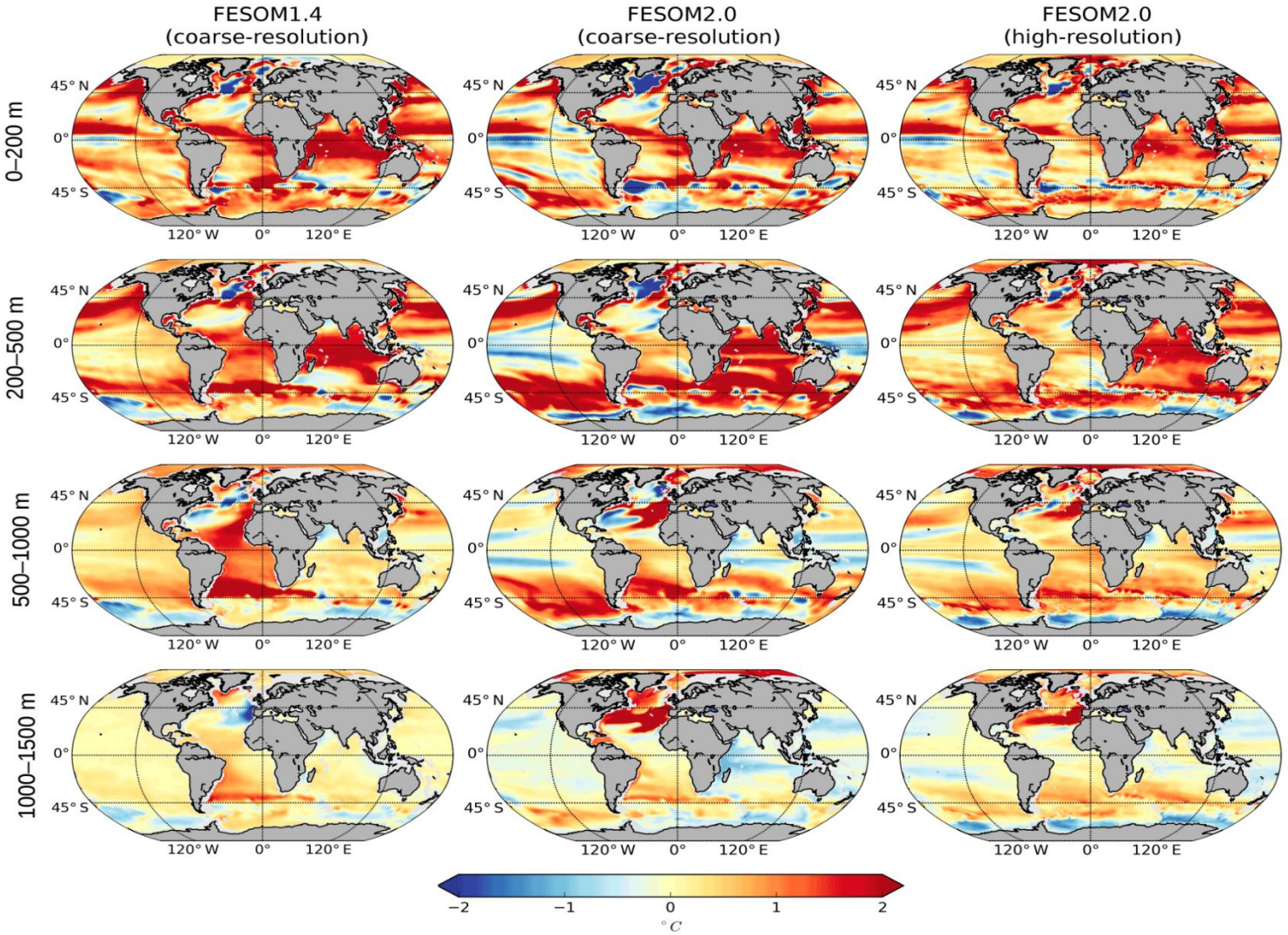
Finite-Element Sea-Ice-Ocean model





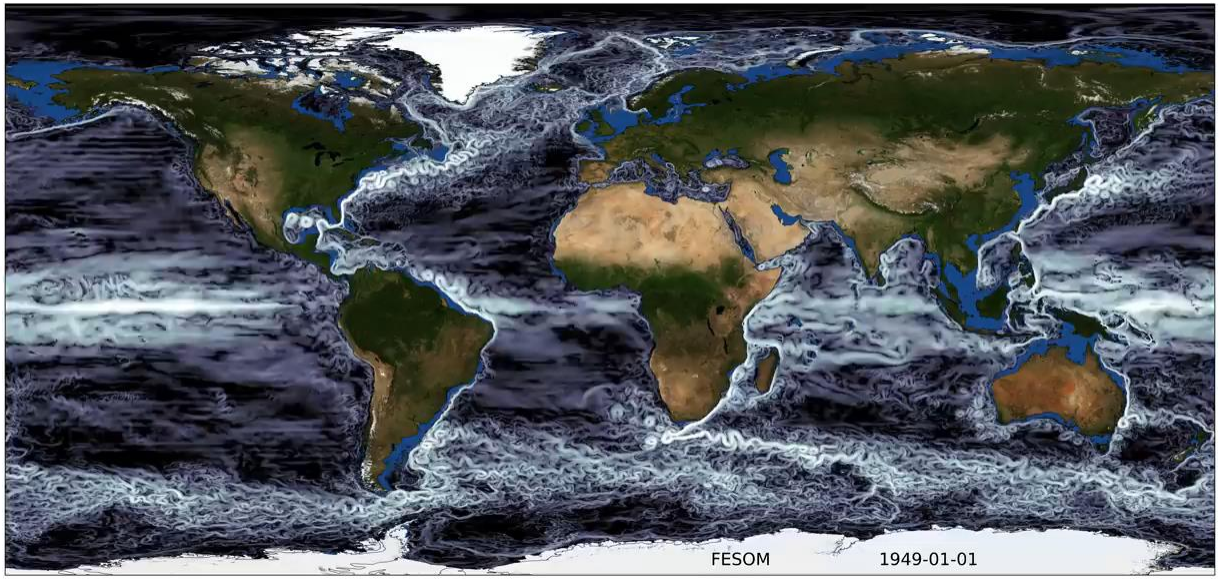
Example of global very low resolution FESOM mesh.

AWI



The departure of simulated potential temperature averaged over 1998–2007 from WOA2005 climatology, averaged over depth ranges. The left and middle columns correspond to the simulations performed with FESOM1.4 and FESOM2, respectively, on the coarse resolution reference mesh. The right column corresponds to FESOM2.0 on the global mesh with a resolution of 15 km

High resolution simulations



FESOM2 20-year run. 5^E6 node grid.
computation, D. Sidorenko;
graphics, N. Koldunov

Может ли современная модель глобального океана предсказать изменчивость гидродинамических полей?

Outline

- Intro
- Observation systems
- Modelling
- **Data assimilation methods**
- NWP / operational / climate applications
- Skills

Data assimilation

based on simulation results from the global cloud-resolving model NICAM and NASA satellite imagery. Courtesy of Ryuji Yoshida.

- sparse data w.errors
- numerical model w.errors
- DA: how to combine info from data and model to improve model forecasts
- DA methods:
  - variational (3D-Var, 4D-Var)
  - sequential (derived from Kalman filter: EKF, SEEK, EnKF, LETKF…)
  - use of machine learning

Variational DA

numerical model:

$$\boldsymbol{x}(t_k) = M_{k-1,k}\left(\boldsymbol{x}(t_{k-1})\right), \quad k \in [0, K],$$

(S. Laroche 2005)

minimize a cost function:

$$\begin{aligned} J \quad = \quad & \frac{1}{2}[\boldsymbol{x}(t_0) - \boldsymbol{x}^{\mathrm{b}}(t_0)]^T \mathbf{B}_0^{-1}[\boldsymbol{x}(t_0) - \boldsymbol{x}^{\mathrm{b}}(t_0)] \\ & + \frac{1}{2}\sum_{k=0}^{K}\left(\mathbf{H}_k M_{0,k}(\boldsymbol{x}(t_0) - \boldsymbol{x}^{\mathrm{b}}(t_0)) - \boldsymbol{d}_k\right)^T \\ & \mathbf{R}_k^{-1}\left(\mathbf{H}_k M_{0,k}(\boldsymbol{x}(t_0) - \boldsymbol{x}^{\mathrm{b}}(t_0)) - \boldsymbol{d}_k\right), \end{aligned}$$

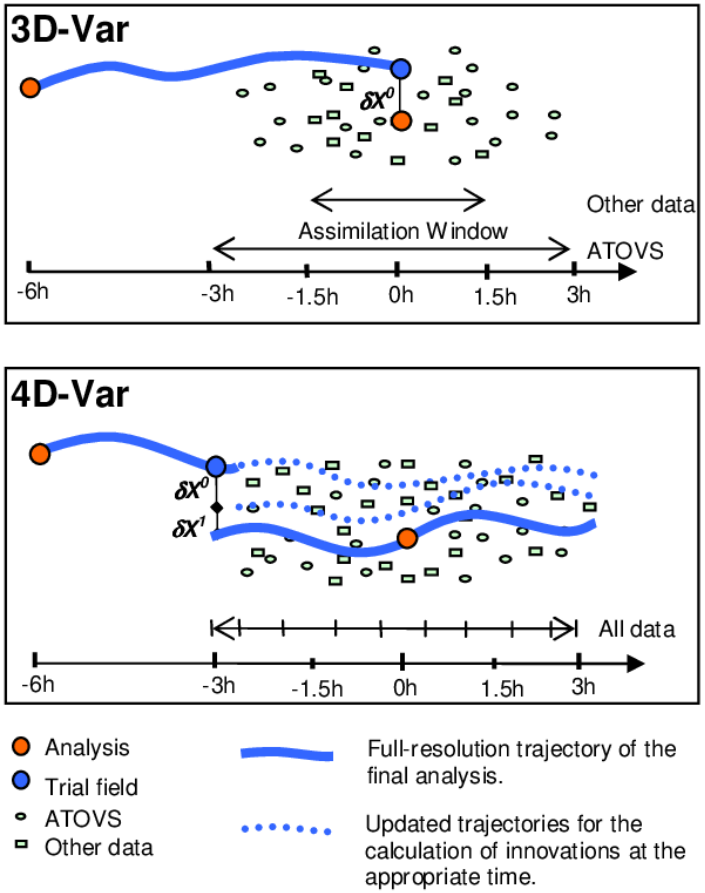


Fig. 1: Schematics of 6-h data assimilation cycles for the global forecasting system: the former 3D-Var (top panel) and the new implemented 4D-Var (bottom panel)

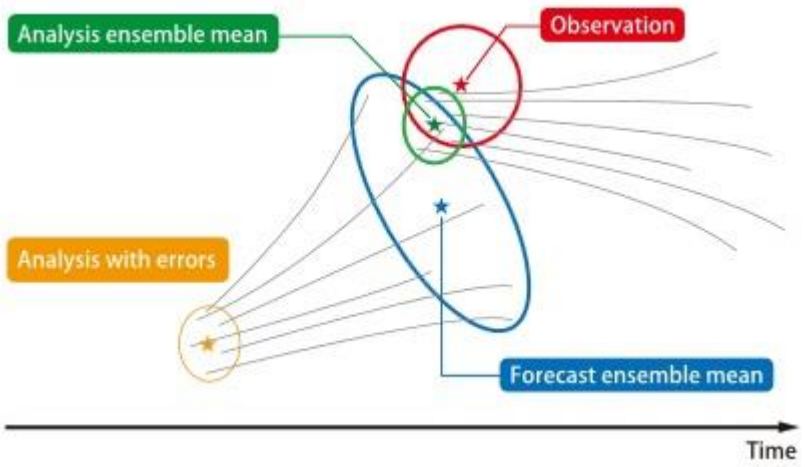
Ensemble Kalman filter

numerical model:

$$\boldsymbol{x}_i^{\mathrm{f}}(t_k) = M_{k-1,k}(\boldsymbol{x}_i^{\mathrm{a}}(t_{k-1})) + \boldsymbol{\eta}_i(t_k), \quad i \in [1, N],$$

ensemble covariance matrix:

$$\mathbf{B}_{\mathrm{e}} = \frac{1}{N-1} \sum_{i,j} \tilde{\boldsymbol{x}}_i \tilde{\boldsymbol{x}}_j^T.$$



ensemble Kalman filter equation:

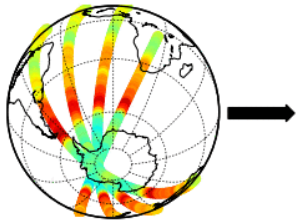
$$\mathbf{X}^{\mathrm{a}}(t_k) = \mathbf{X}^{\mathrm{f}}(t_k) + \mathbf{B}_{\mathrm{e}}(t_k)\mathbf{H}_k^T \left[\mathbf{H}_k \mathbf{B}_{\mathrm{e}}(t_k) \mathbf{H}_k^T + \mathbf{R}_k \right]^{-1} \mathbf{D}_k,$$

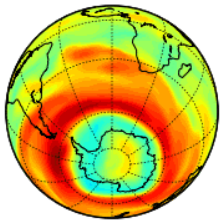
$$\mathbf{D}_k = \mathbf{Y}_k - \mathbf{H}_k \mathbf{X}^{\mathrm{f}}(t_k)$$

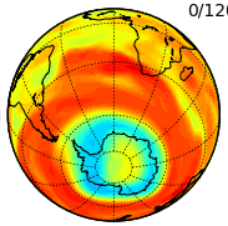
INTERNATIONAL SPACE SCIENCE INSTITUTE

International Team

0/120

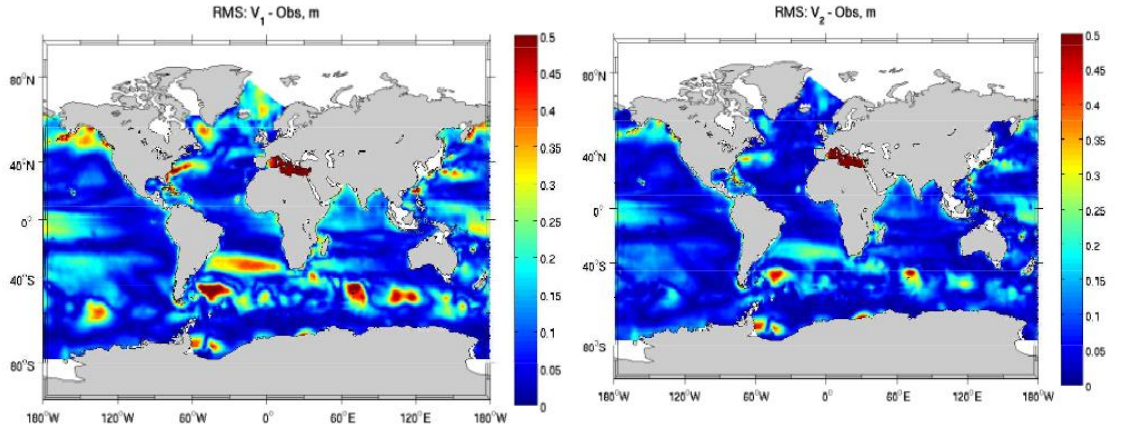

Observations


Analysis


Model

Canada

Example: how DA corrects model initial conditions



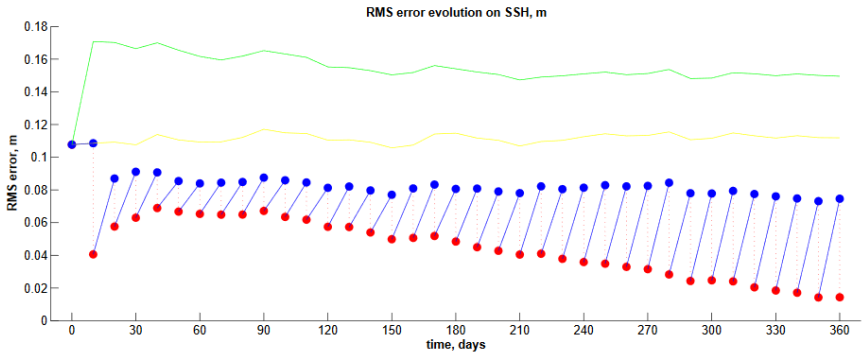


Fig. 3. Evolution of RMS error of SSH for the world ocean (except zones corresponding to RIO05 MDT location in the data see Fig. 1). The green and yellow solid lines show the errors corresponding to the V_1 and V_2 free simulations (without assimilation), respectively. The blue lines with bullets represent the V_3^f 10-day model forecasts, while the dotted red lines correspond to the V_3^a analysis. V_1 model which was spun up was re-initialized at the initial time with the initial condition of V_2.

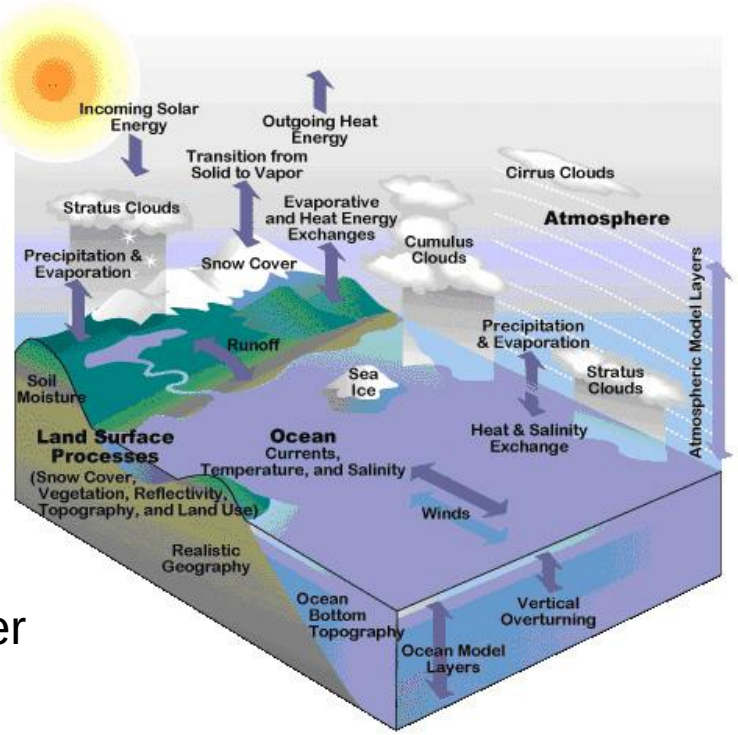
Canada

Outline

- Intro
- Observation systems
- Modelling
- Data assimilation methods
- **NWP / operational / climate applications**
- Skills

Climate coupled models

- ocean and atmosphere models talk to each other: 2-way coupling

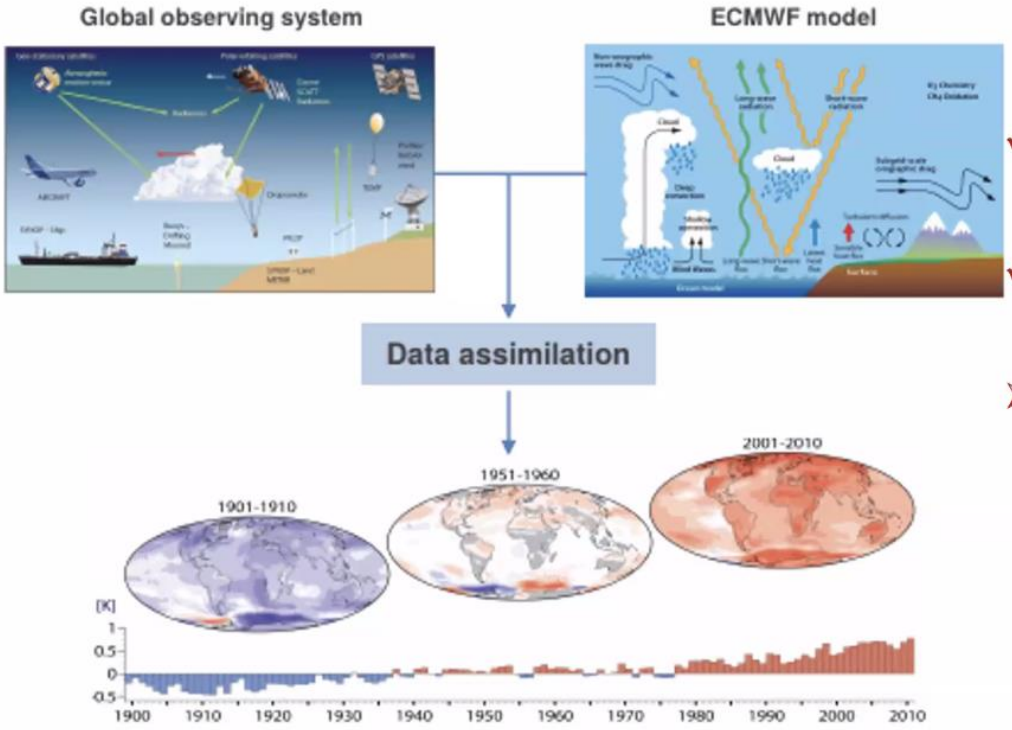


What's in a global climate model? The Community Climate System Model (CCSM version 3) that is run with the supercomputer at the National Center for Atmospheric Research incorporates data about all of the natural processes shown in this diagram to simulate Earth's complex climate system. *UCAR*

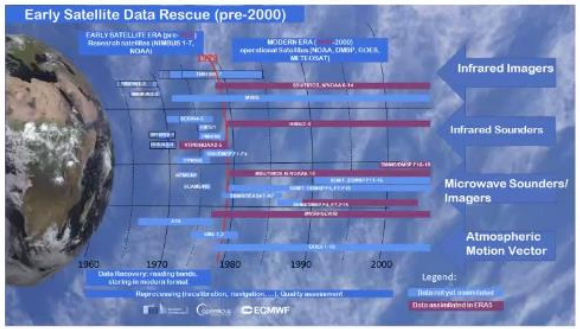
Monitoring the planet: Copernicus Reanalysis

Climate Change

Reanalysis uses past observations with today's weather forecast model



- ✓ Complete: combining vast amounts of observations into (global) fields *"reanalysis is a smart machine"*
- ✓ Consistent: use the same physical model and data assimilation system throughout
- ✓ Convenient: "maps without gaps", always available in the same way
- ➢ provide an uncertainty estimate



ECMWF Copernicus Europe's eyes on Earth European Commission

Monitoring the planet: Copernicus

Climate Change

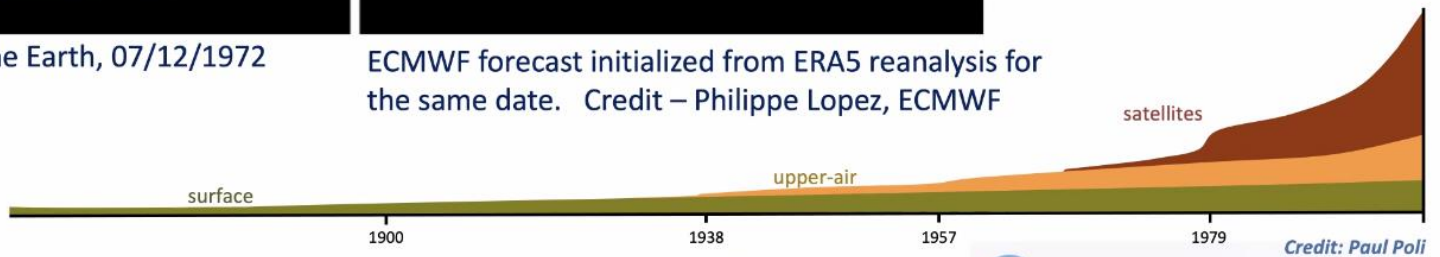
Future of reanalysis

Apollo 17 image of the Earth, 07/12/1972
Credit - NASA

ECMWF forecast initialized from ERA5 reanalysis for the same date. Credit – Philippe Lopez, ECMWF

ERA6:

- Coupled ocean-atmosphere
- Better representation of key atmosphere-ocean processes and feedbacks
- C3S satellite data rescue
- ERA6L with enhanced land data assimilation



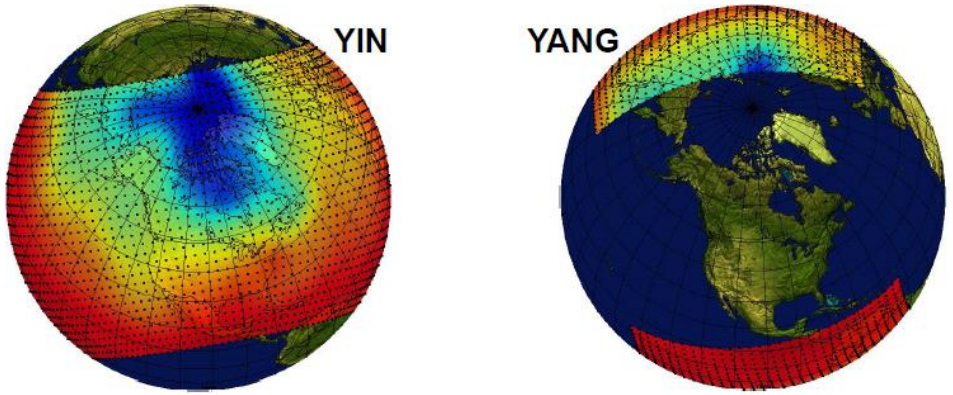
Credit: Paul Poli

ECMWF Copernicus Europe's eyes on Earth European Commission

ECCC's Global Deterministic Prediction System (GDPS)

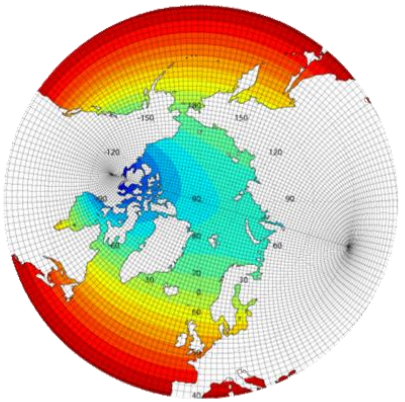
- GEM atmospheric model
  - Current ECCC's NWP system
  - Coupled GDPS 10 day forecasts: atmosphere-ocean-ice
- 4D-EnVar data assimilation:
  - Variational approach using 4D ensemble covariances from EnKF
  - Hybrid covariances by averaging the ensemble covariances with the static NMC-method covariances
- Data assimilated by the GDPS:
  - radiosondes, aircraft
  - Surface report (SYNOP, SHIP, BUOYs)
  - ATOVS
  - ATMS
  - SSMIS
  - AIRS/IASI/CrIS
  - GeoRad
  - ASCAT
  - AMVs
  - GPS-RO

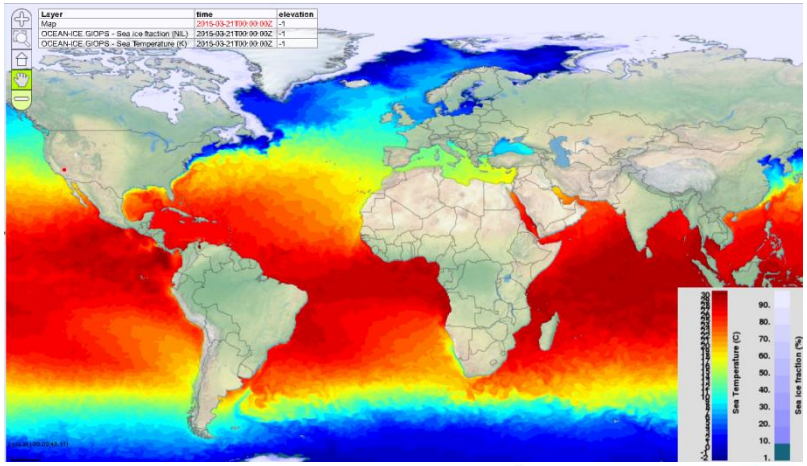
Global, Δx =25km



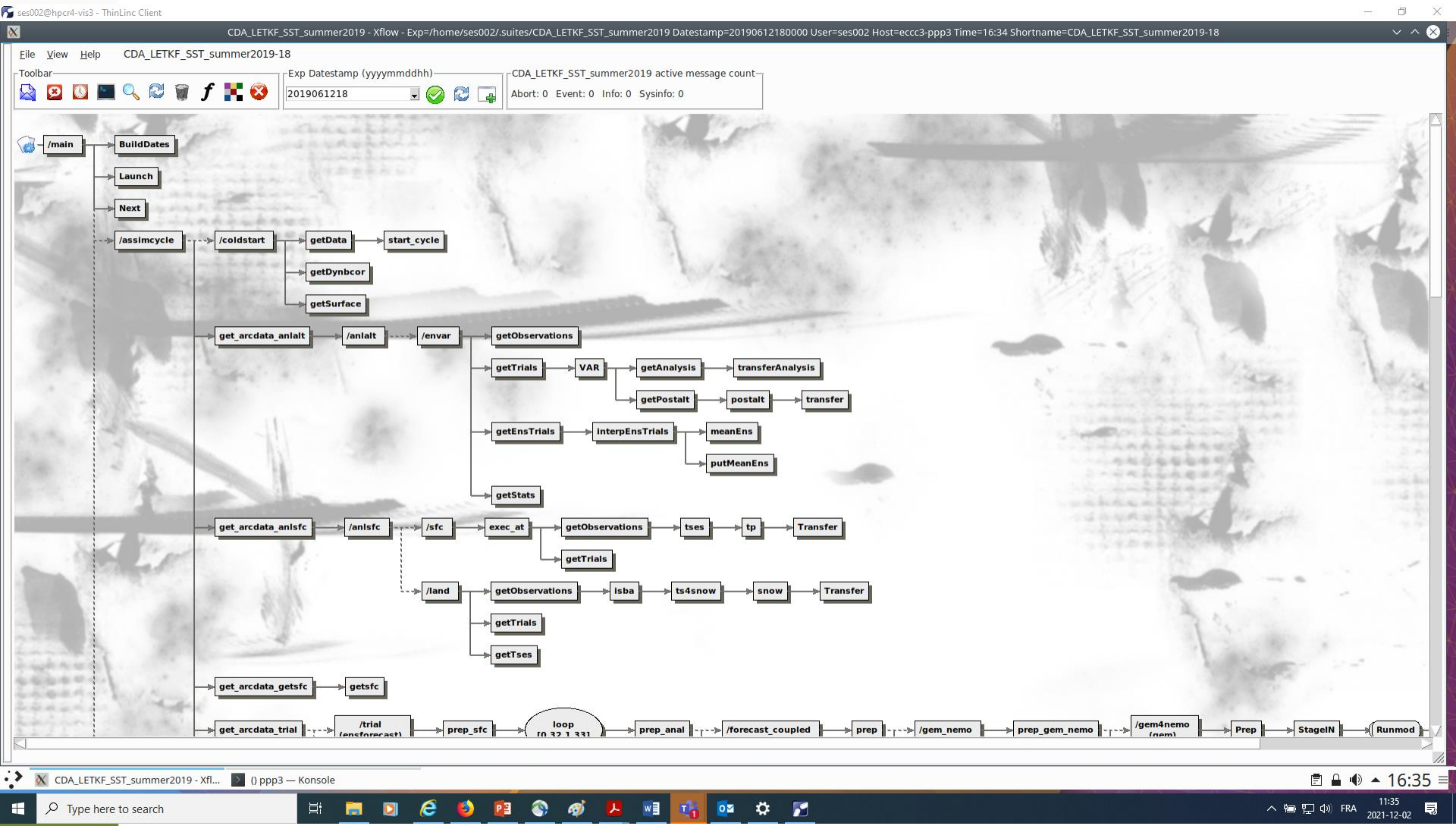
Ice-ocean modelling and data assimilation with NEMO + CICE

- Global Ice-Ocean Prediction System (GIOPS), NEMO-CICE coupled model 1/4° (ORCAS025)
  - Seasonal forecasting
  - Coupled GDPS 10 day forecasts: atmosphere-ocean-ice
- Mercator Ocean Assimilation System SAM2 (SEEK):
  - Sea surface temperature daily
  - Temperature and salinity profiles weekly
  - Sea level anomaly from satellite altimeters weekly
- 3DVar Ice analysis:
  - SSM/I, SSM/IS, ASCAT, AVHRR
  - CIS charts and image analyses
- SST OI analysis:
  - in situ data, AVHRR, AMSR-E, ATSR
  - foundation SST
  - background: previous day analysis

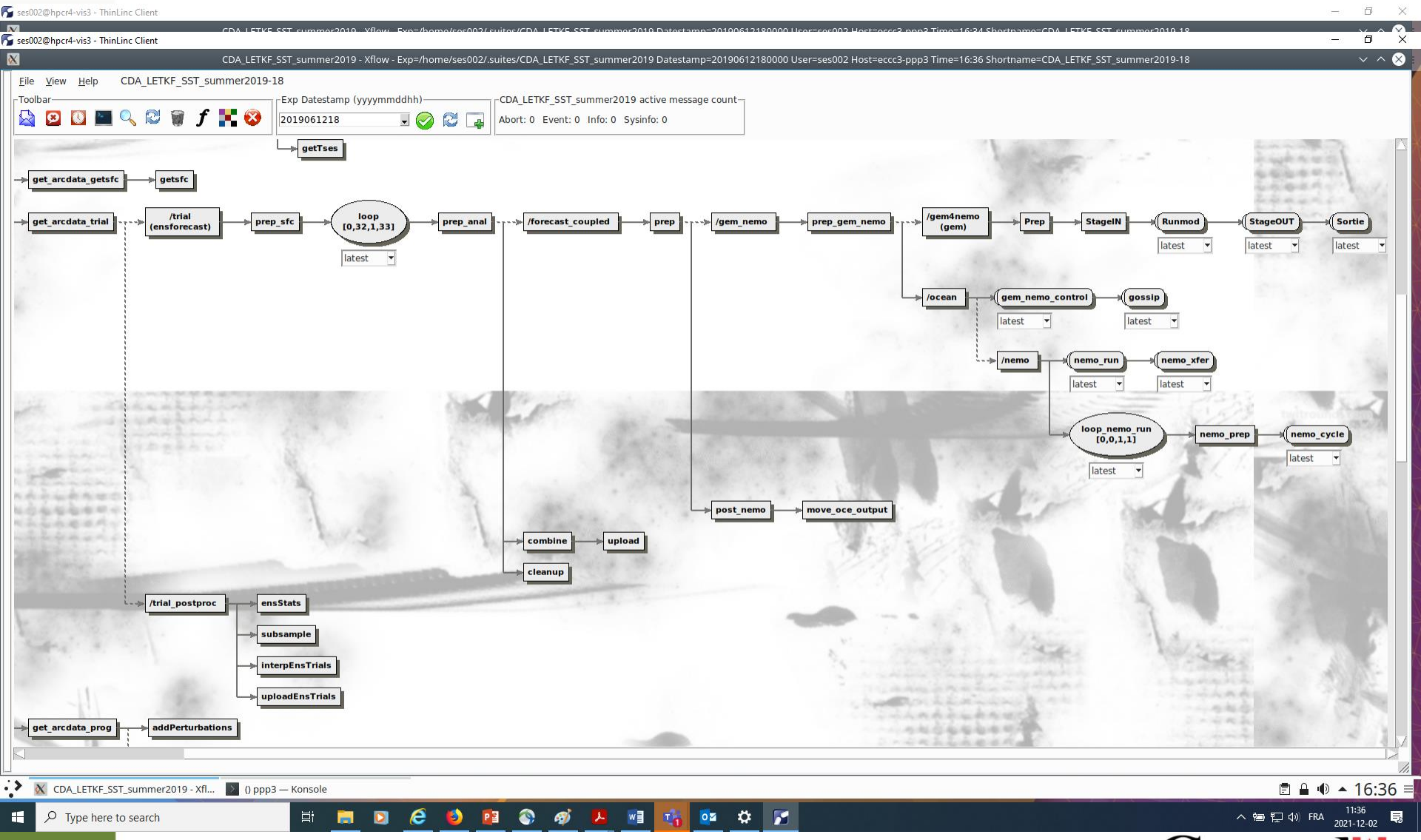




Cycle launcher: coupled ensemble data assimilation system



Cycle launcher: coupled ensemble data assimilation system



Motivation: Impact of Coupling on Forecasts for Typhoon Neoguri

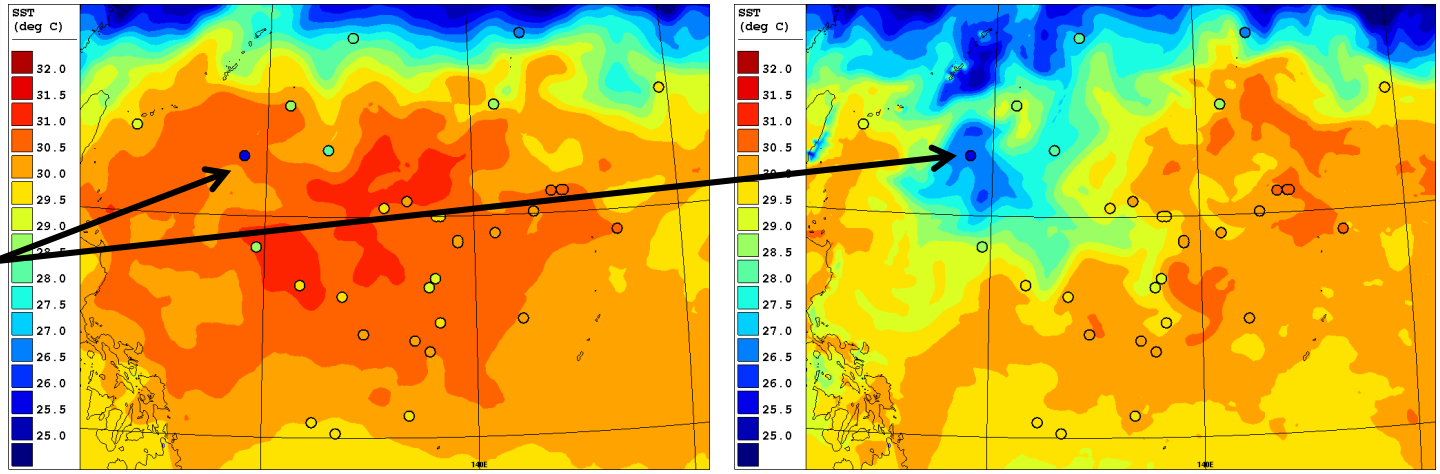
96h forecasts, valid 00Z, July 10, 2014

Smith et al., MWR, 2018

SST from drifter obs.
Much better agreement of cold wake in Coupled forecasts

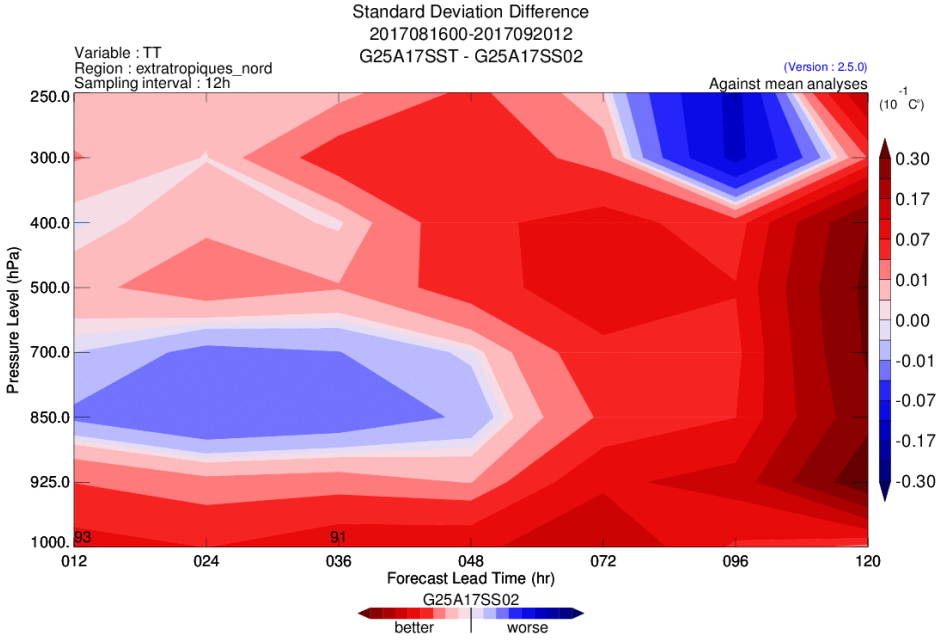
a) Forced (uncoupled) SST

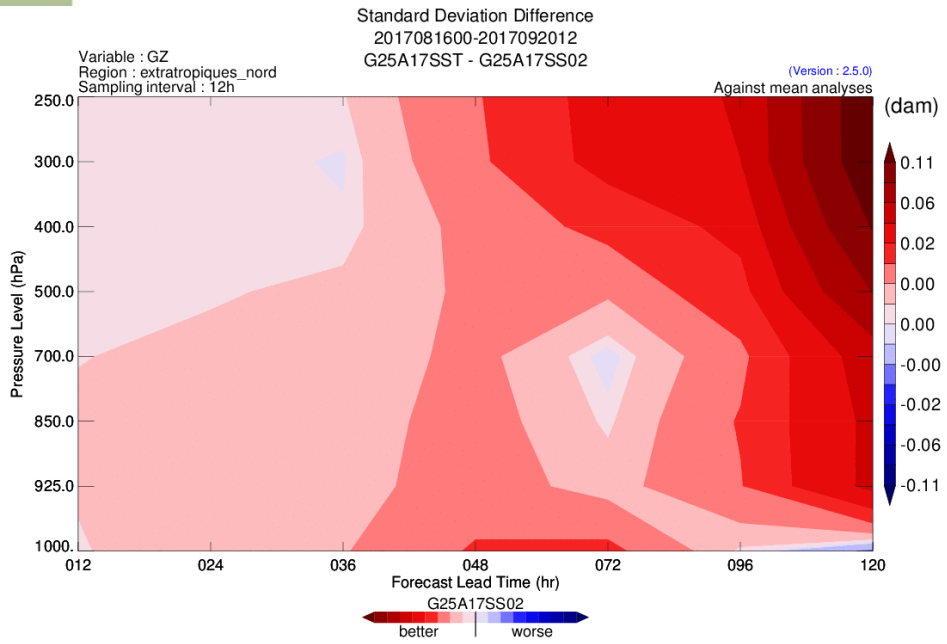
b) Coupled SST



STD difference on atmospheric T and GZ with respect to own analyses as a function of forecast lead time.

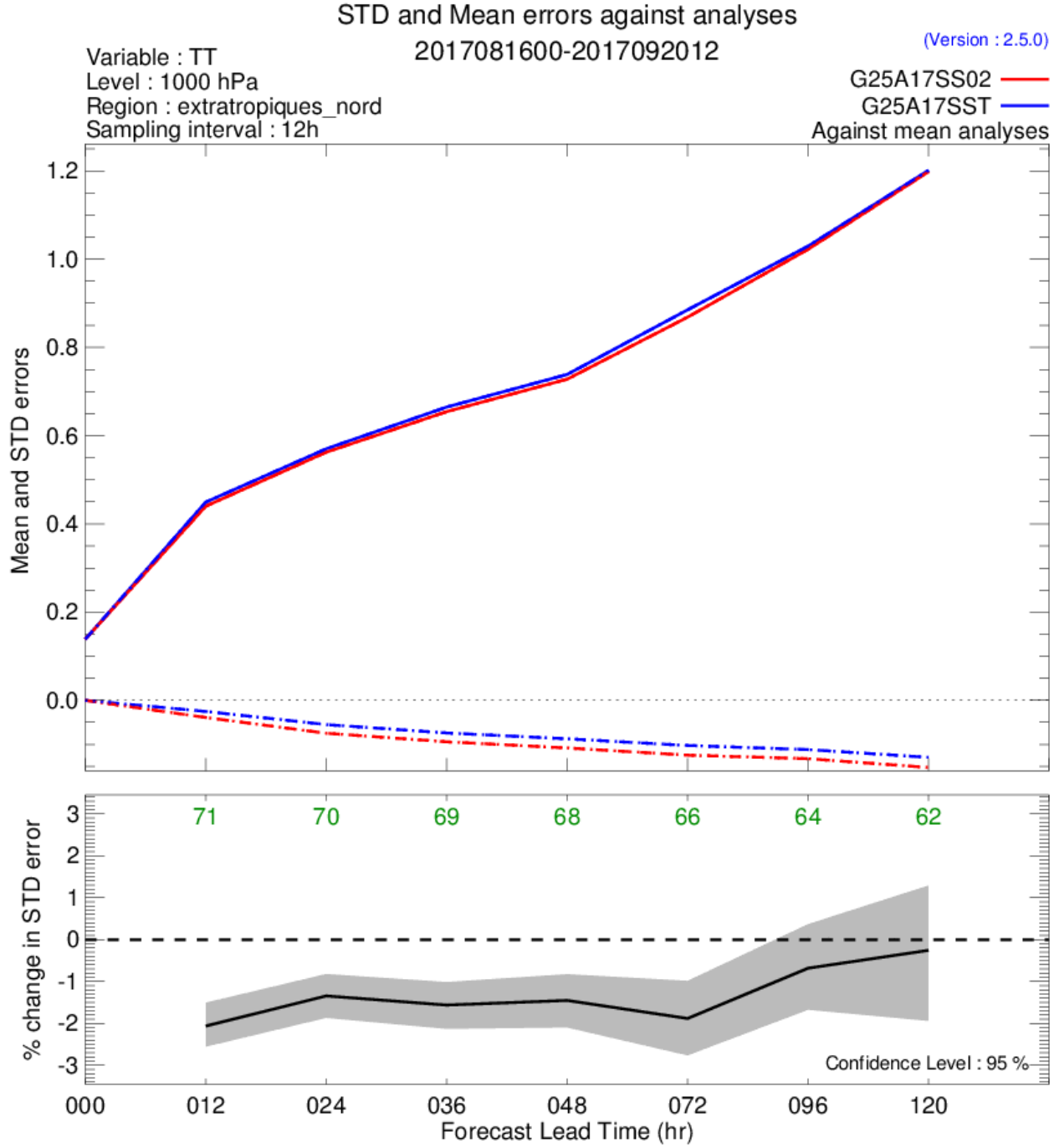
Region: Northern Extratropics

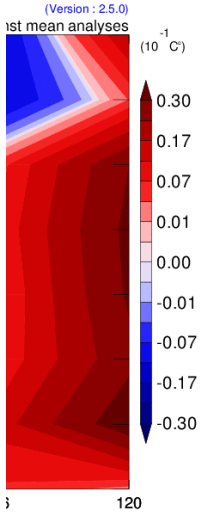


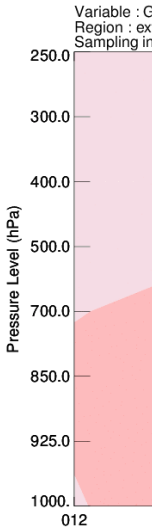


Canada

STD dif
analyse
Region: N







to own

nada

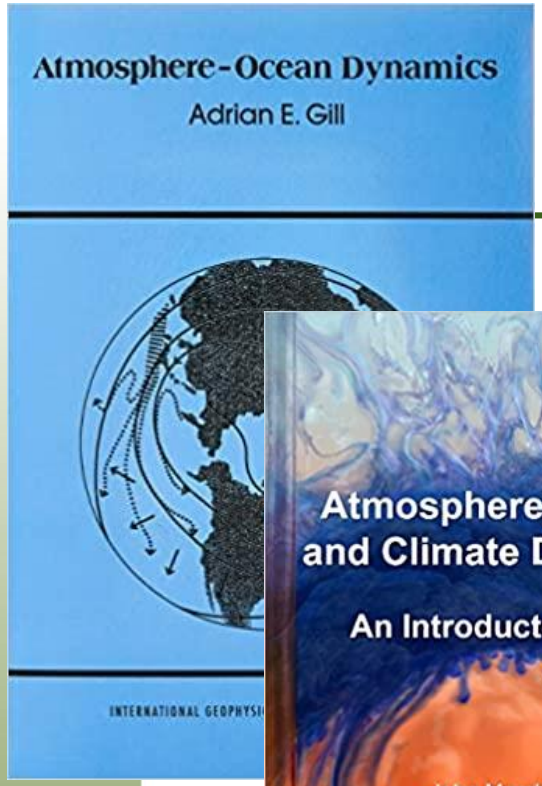
Outline

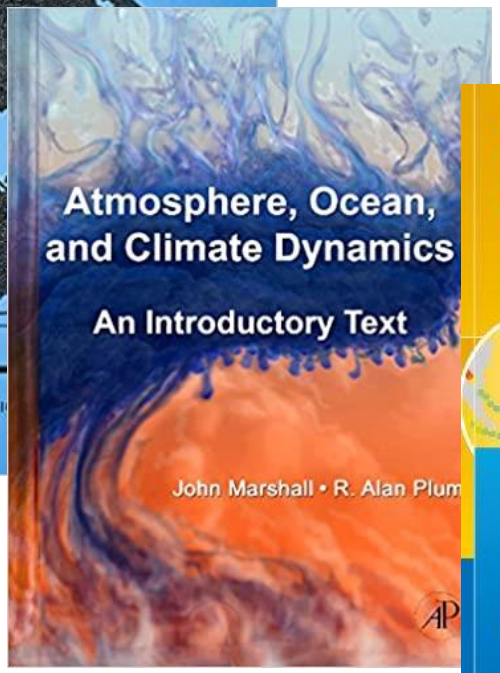
- Intro
- Observation systems
- Modelling
- Data assimilation methods
- NWP / operational / climate applications
- **Skills**

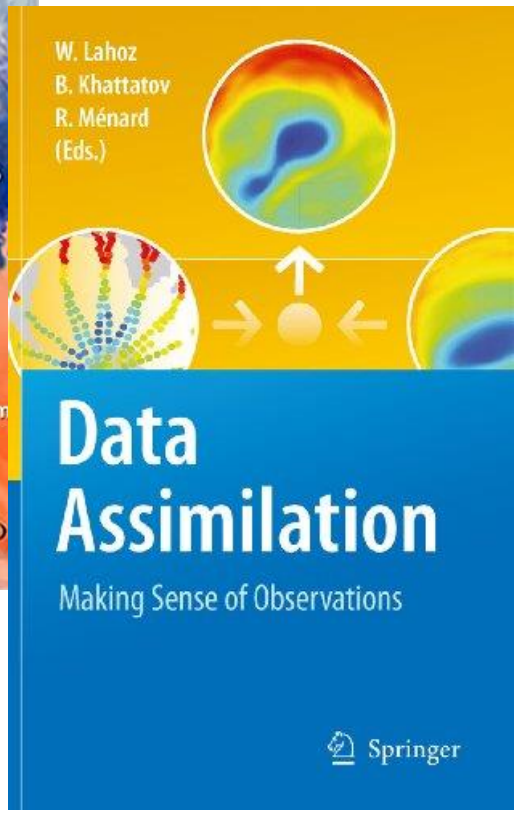
Полезные навыки в нашей работе

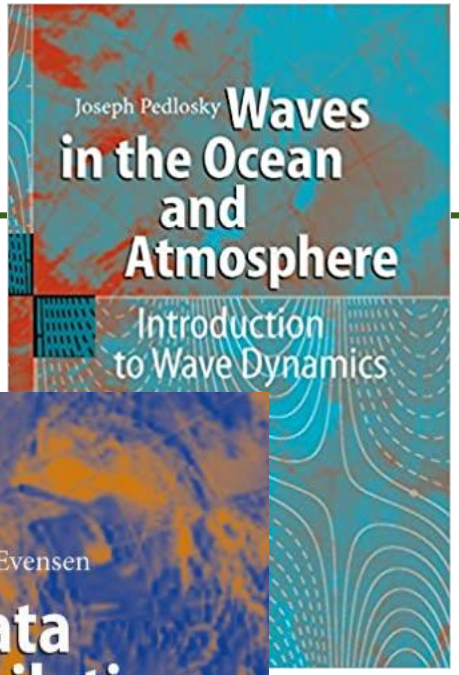
- bash / ksh scripting, linux environment
- Fortran
- python
- matrix and variational analysis, numerical modelling methods
- error statistics
- satellite retrieval algorithms
- ocean-ice-atmosphere-waves thermodynamics, interactions
- global ocean/atmosphere circulation
- языки

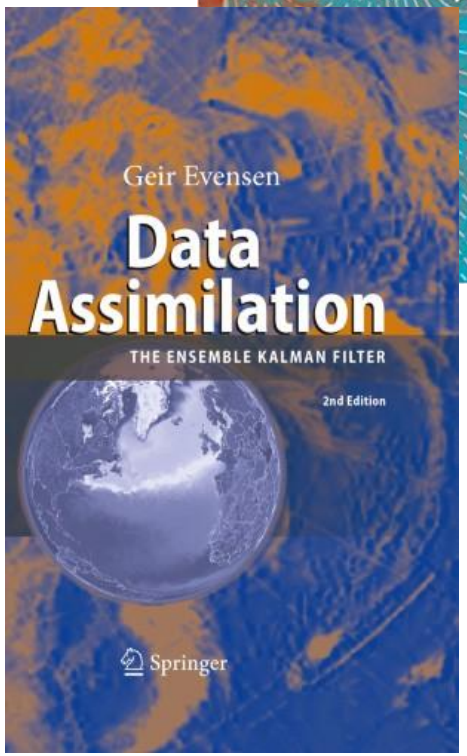
Хорошие книги



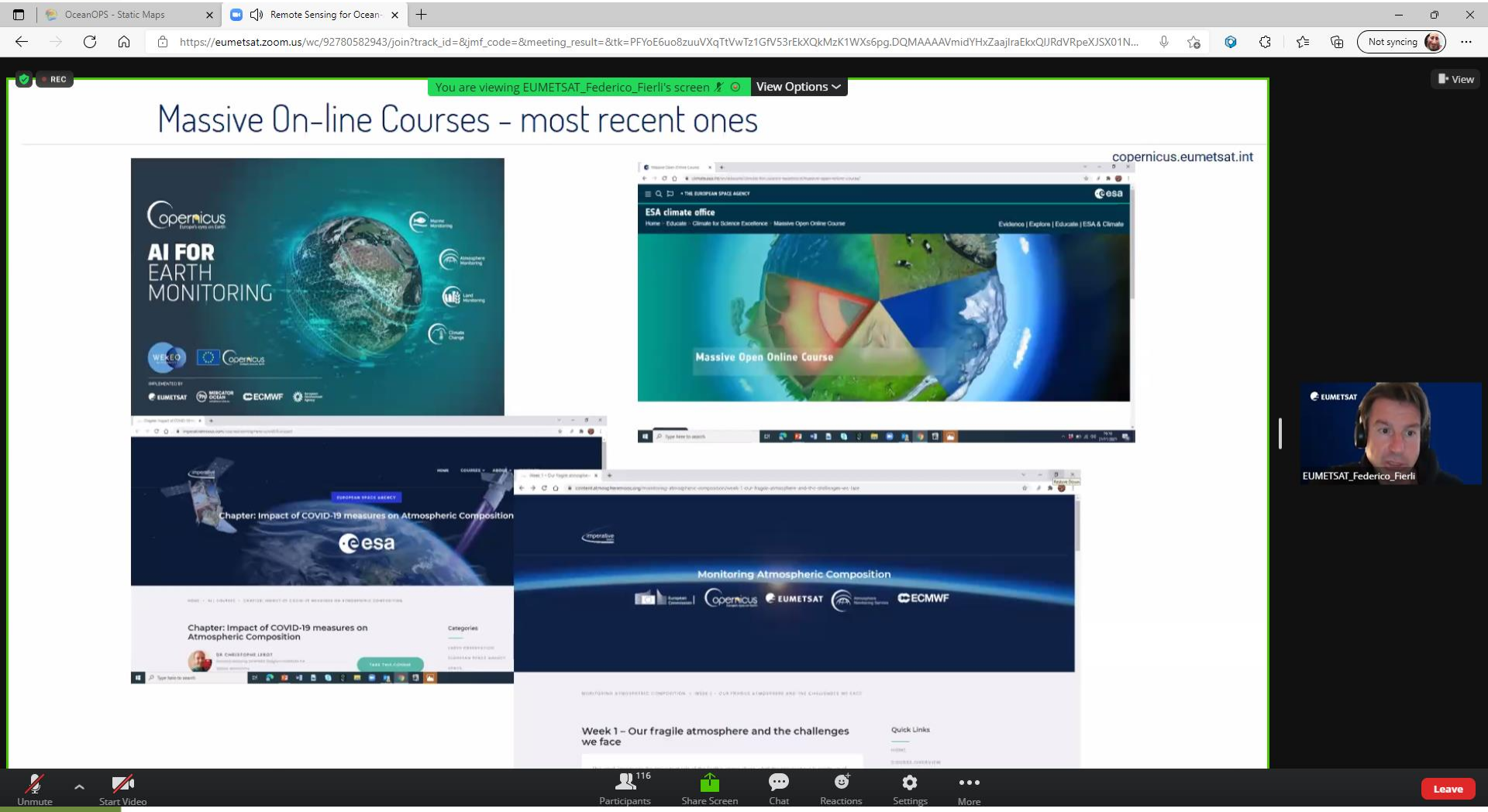








Интересные ресурсы



ECMWF online courses & trainings

European Centre for Medium-... (GB) https://www.ecmwf.int/en/learning

Search

ECMWF

Search site... Help Log in

Home About Forecasts Computing Research Learning Publications

Training | Workshops | Seminars | Education material

Training

Our training courses are broken down into modules so that you can take each one separately over a timescale that suits you.

Guidelines for training course applications

Workshops and Annual Seminar

We run workshops throughout the year and a week-long Annual Seminar on a specific topic every September.

Past workshops and Annual Seminars

Informal seminars

We regularly organise informal seminars given by internal or external speakers on a range of topics.

Past informal seminars

Resources

We provide learning materials related to our courses and workshops, NWP lecture notes, and eLearning modules.

eLearning - online resources

About Forecasts Computing Research Learning Publications

Спасибо!

Sergey.Skachko@canada.ca
+1 438 391 9750