The ECMWF operational system

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ECMWF

Highlights for recent changes of ECMWF's operational system

- Move production from Reading data centre (Cray HPC) to Bologna data centre (ATOS HPC)
  - All production started on October 18 2022
  - Data handling system moved as well
- Major science upgrade in June 2023 for the atmospheric model:
  - Upgrade of the resolution of the medium range ensemble system (ENS) from 18 to 9 km
  - Extended range no longer starts from the ENS system but run continuous from day 0
    - Daily forecasts rather than bi-weekly
    - 101 members rather than 51 members
  - The increase in HPC capacity made these changes possible
- While these are not ocean forecasting changes, they still have consequences for external down stream ocean forecasting systems using our atmospheric fields as forcings
- No changes yet for the ocean modelling and data assimilation system, but we are finalizing a major upgrade
  - Bulk of my talk

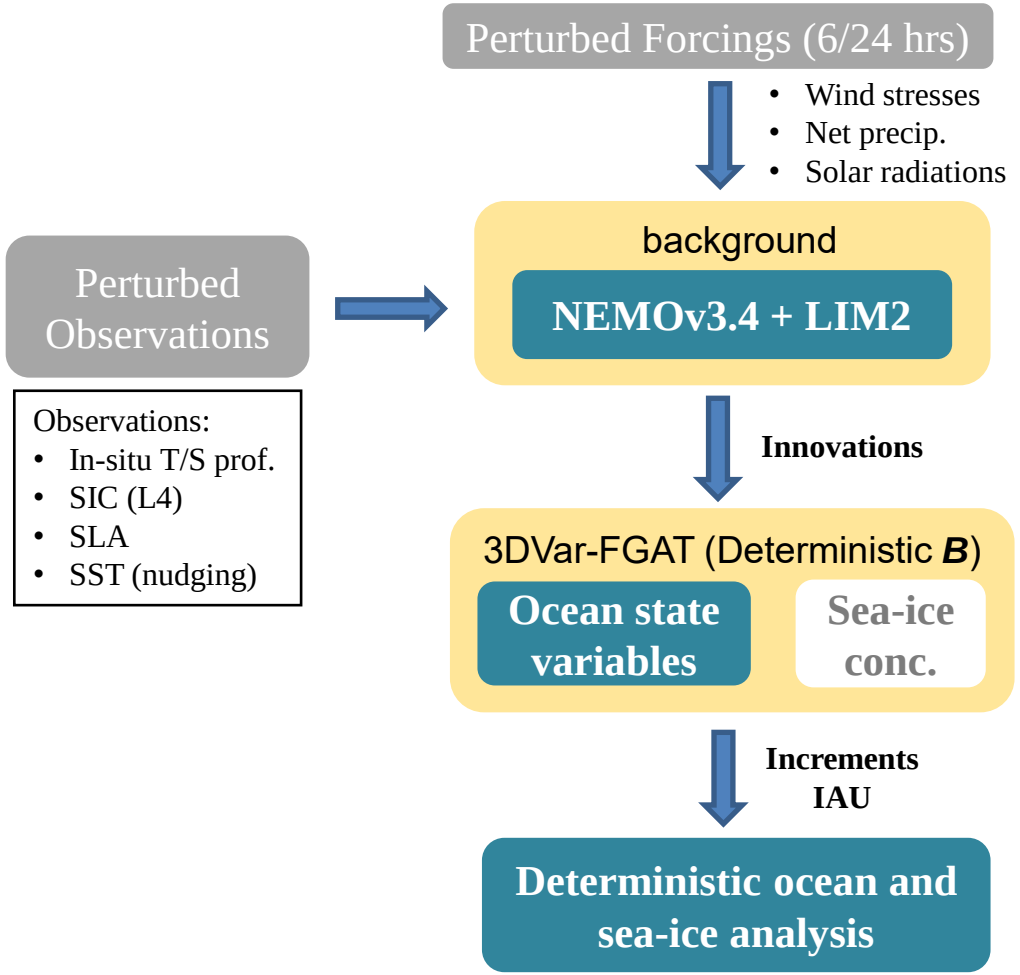
Summary of current ECMWF operational systems

- Ocean model configurations
  - Current ocean model is based on NEMO V3.4.1 with local ECMWF modifications
  - Same ocean grid with about 0.25-degree resolution used for all operational systems
- Ocean analysis systems (reanalysis and real-time):
  - ocean5: NEMOVAR 3D-VAR FGAT
    - T/S/SLA/SIC observations, SST via relaxation
- All forecasting systems are coupled (atmospheric resolution list below)
  - HRES CY48R1 (27/6-2023) 9 km deterministic 10 days twice daily
  - ENS CY48R1 9 km 51 members 15 days twice (0z/12z) daily
  - Monthly CY48R1 36 km 101 member 46 days daily 0z starting from day 0 (not from day 15 ENS)
  - SEAS5 CY43R1 (November 2017) 36 km 7 months every month, 13 months every 3 months
- We use hindcasts to calibrate forecasts
  - A lot of product are calibrate based on model climate

Next major ocean modelling upgrade

- Upgrade the ocean model from NEMO V3.4 to NEMO V4.0
  - New sea ice model SI^3
    - Multi-category sea ice is a first for us
- Upgrade use of forcing fields from ERA-Interim to ERA5 for the reanalysis
  - Higher atmospheric resolution
  - Hourly forcings
  - Diurnal cycle in the ocean initial conditions
- Real time system will also use hourly forcing from NWP
- Upgrade the data assimilation to a later version of NEMOVAR
- First milestone is to put a new ocean DA system in production

Ocean and sea-ice reanalysis at ECMWF: ORAS5

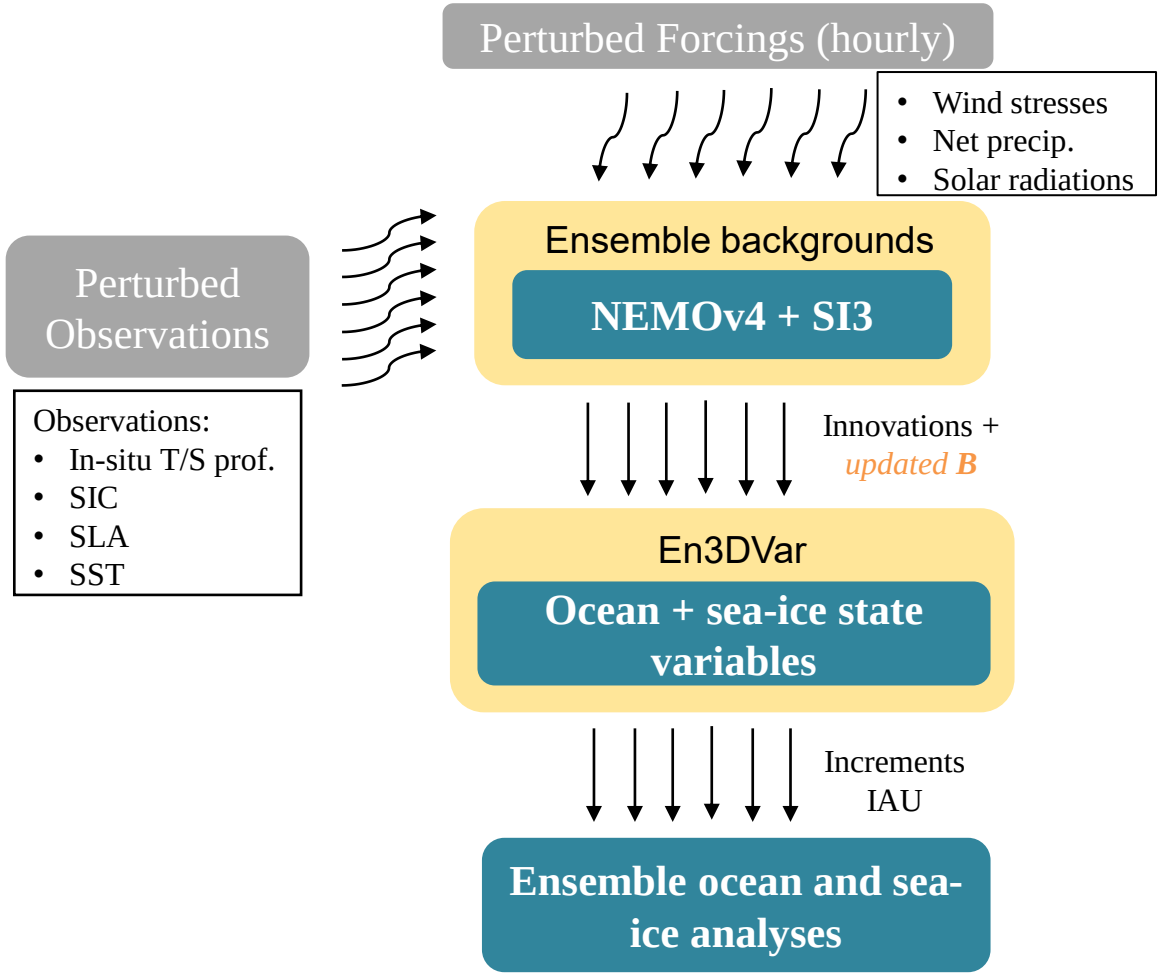


Overview of the ORAS5/OCEAN5 system

ORAS5 is deterministic ocean and sea-ice reanalysis

- *5 member generated with perturbed forcing and observation inputs.*
- *Each member is a deterministic analysis produced with 3DVar-FGAT approach.*
- *No feedback between ensemble backgrounds and Covariance **B***

Ocean and sea-ice reanalysis at ECMWF: ORAS6

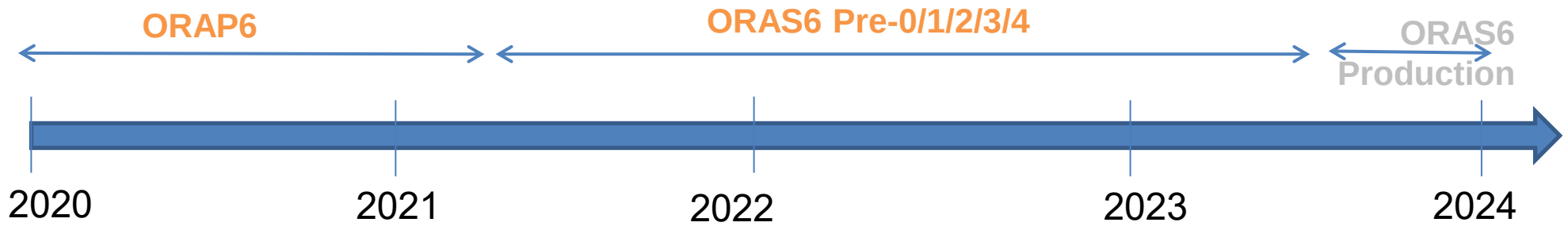


Overview of the ECMWF ORAS6 system

ORAS6 is the new ECMWF ensemble ocean and sea-ice reanalyses. ORAS6 will replace ORAS5 to provide ocean and sea-ice initial conditions for all ECMWF coupled forecasts in 2024 (including ERA6).

- *NEMOv4 + SI3 (¼ deg +75 level)*
- *Assimilates ocean in-situ and surface observations*
- *Use En3DVar FGAT scheme, 11 members*
- *Covariance **B** is updated every cycle with ensemble backgrounds, generated by perturbed forcings and observations*

ORAS6: Timeline



	Forcing		Model		Data Assimilation				Ens. Gen.		Observations			
	Atmos.	FWB	Ocean	Sea-ice	B cov.	Bias Corr.	SST	Sea-ice	Ens num	Pert.	SL	Insitu	SIC	SST
ORAS5/ OCEAN5	ERA40/ERA-int (6/24hr)	GRACE+ MSLA	NEMOv3.4 ¼ deg., 75 levels	LIM2 (single-cat)	3DVar FGAT	a-prior + online	Nudging	Weekly-coupled	5	V3: Obs + forcing	DT2018	EN3	OSTIA L4	HadISST2+OSTIA L4
ORAS6	ERA5 hourly	New FWB distr.	NEMO4 ¼ deg., 75 levels	SI3 (multi-cat.)	En3DVar + Hybrid-B	2-step offline + online	En3DVar	Single minimization	11	V4: Obs + forcing	DT2021	EN422	OSI-SAF L3 (v3)	OSTIAv2 L4

Evaluation of ORAS6: SST

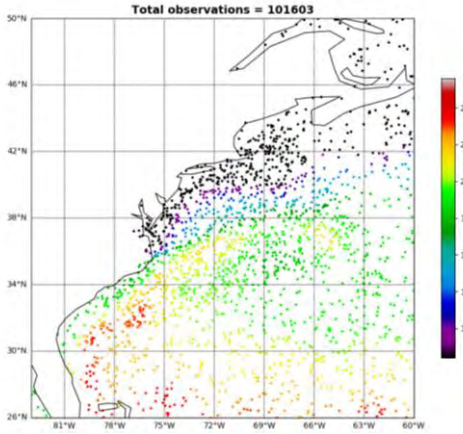
OSTIAv2 SST data is directly assimilated in the ORAS6 system

- This has greatly reduced SST biases in the GS region but only if *ensemble based vertical diffusion tensor* is used.
- Improvement also attributed to ERA5 forcing and improved upper ocean mixing in the physical model.

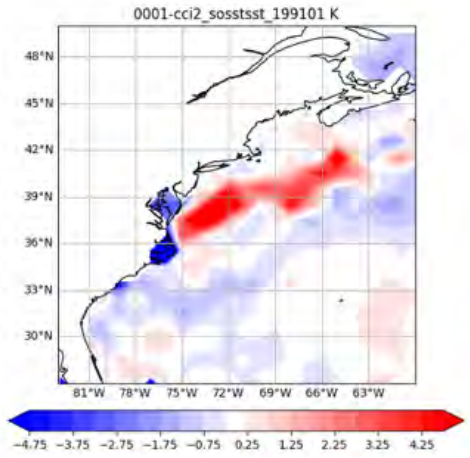
SST biases in the Gulf Stream regions (Jan 1991)

ORAS6 (SST DA)

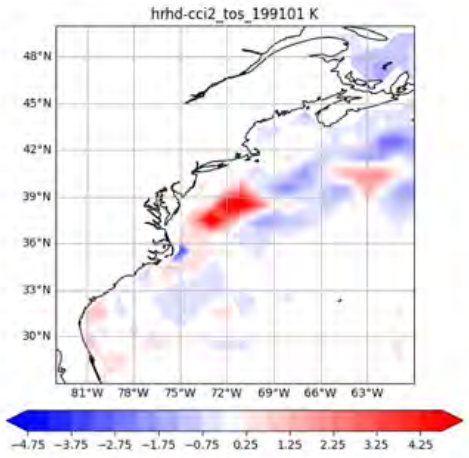
OSTIA SST



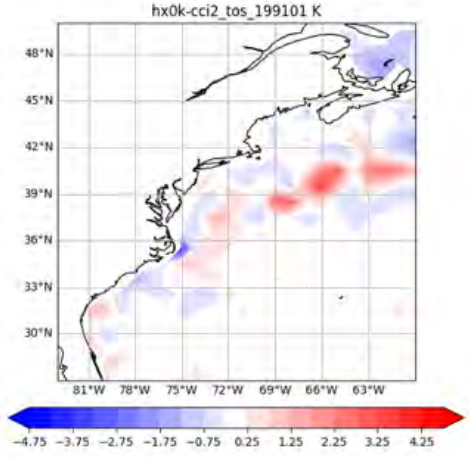
ORAS5 (SST nudging)



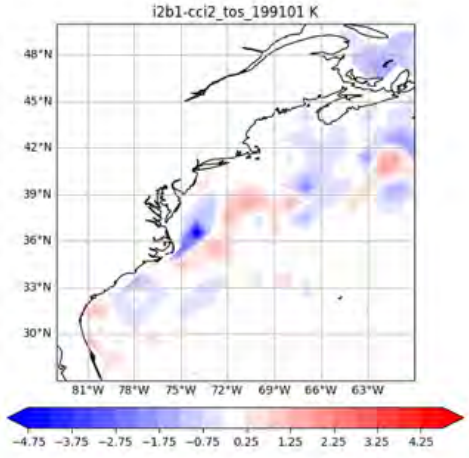
Prep-1



Prep-2



Prep-3.5



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Plans beyond the new ocean reanalysis system

- Next 6 months:

1. Upgrade the seasonal forecasting system (SEAS6) to use NEMO V4 and produce hindcasts for calibration (SEAS6)
    1. Produce hindcasts from the ORAS6 BRT system
2. Implement a real time system for the ocean analysis system
3. Implement the forecasting capability for SEAS6 (CY49R2)
    1. Will use the RT ocean DA system
4. Use the output for the ocean reanalysis as input to the next atmospheric reanalysis ERA6 (CY49R2)
    - Same model version for ERA6 and SEAS6

- Next 12 to 18 months:

1. Upgrade all other forecasting systems to use ORAS6 initial conditions and NEMO V4

Outlook for the mid term (beyond the next ocean upgrade)

- Explore the 1/12 degree NEMO eORCA12 configuration
  - Science questions
    - How to initialize the eddies in the right place
    - We need to understand what it gives us in terms of improvements
      - More variability can lead to worse scores in terms of RMSE
  - Technical issues
    - Computational costs
      - One ensemble member is not a problem on our current HPC but 101 in parallel is
    - Dealing with data volumes
      - Again: One member is not a big deal, but 101 is.
- Prepare for next HPC upgrade
  - GPU's/accelerators
- Yet another NEMO model version upgrade
  - Related to the HPC architecture preparation

Digital Twins with the DestinE (or Destination Earth) project

- DestinE: https://stories.ecmwf.int/destination-earth/index.html
- Two digital twins:
  - DT for extremes: Coupled model with 4.4 km atmosphere and operational like ocean settings
    - Short operational like initialized integrations
    - Used to explore impact of atmosphere resolution on extreme weather situation
    - Impact of ocean explored for specific cases like tropical cyclone like structures in the Mediterranean Sea (Medicanes)
      - Ocean initial state and coupling seem to be important here
  - Climate-DT: Long (~30 year) coupled integrations
    - Climate like initialization
    - IFS + two ocean models: NEMO V4 and FESOM2
    - ICON atmosphere+ocean model
    - Subcontracted to a consortium lead by CSC (Finland)
    - https://stories.ecmwf.int/finlands-csc-leads-international-partnership-to-deliver-destination-earths-climate-change-adaptation-digital-twin/index.html

ECMWF perspective on ML/AI/… (I personally prefer data driven models)

- For weather forecasting the machine learning models is a very hot topic:
  - FourCastNet, Pangu-Weather, FengWu, FuXi, GraphCast …
  - Lots of papers showing that they can beat any traditional physics-based numerical models
    - Example for synoptic scale scores on next slide
    - Tropical cyclone tracks are very good, but intensities are way too weak
  - Most (if not all) of them are trained using the ECMWF ERA5 reanalysis
    - They are only as good as the training data sets available
    - Still needs models and data assimilation systems to produce training data as well as initial conditions
- We have developed our own experimental ML model (AIFS) for weather forecasting:
  - https://www.ecmwf.int/en/about/media-centre/aifs-blog/2023/ECMWF-unveils-alpha-version-of-new-ML-model
  - We also run Graphcast, Pangu-Weather and ForeCastNet routinely and produce plots on https://charts.ecmwf.int/
- We **might** consider ML/AI for the ocean and/or the coupled model, but no concrete plans yet

Example of differences in RMSE for 500 hPa geopotential height