The ESA A-TSCV project

Assimilation of Total Surface Current Velocities

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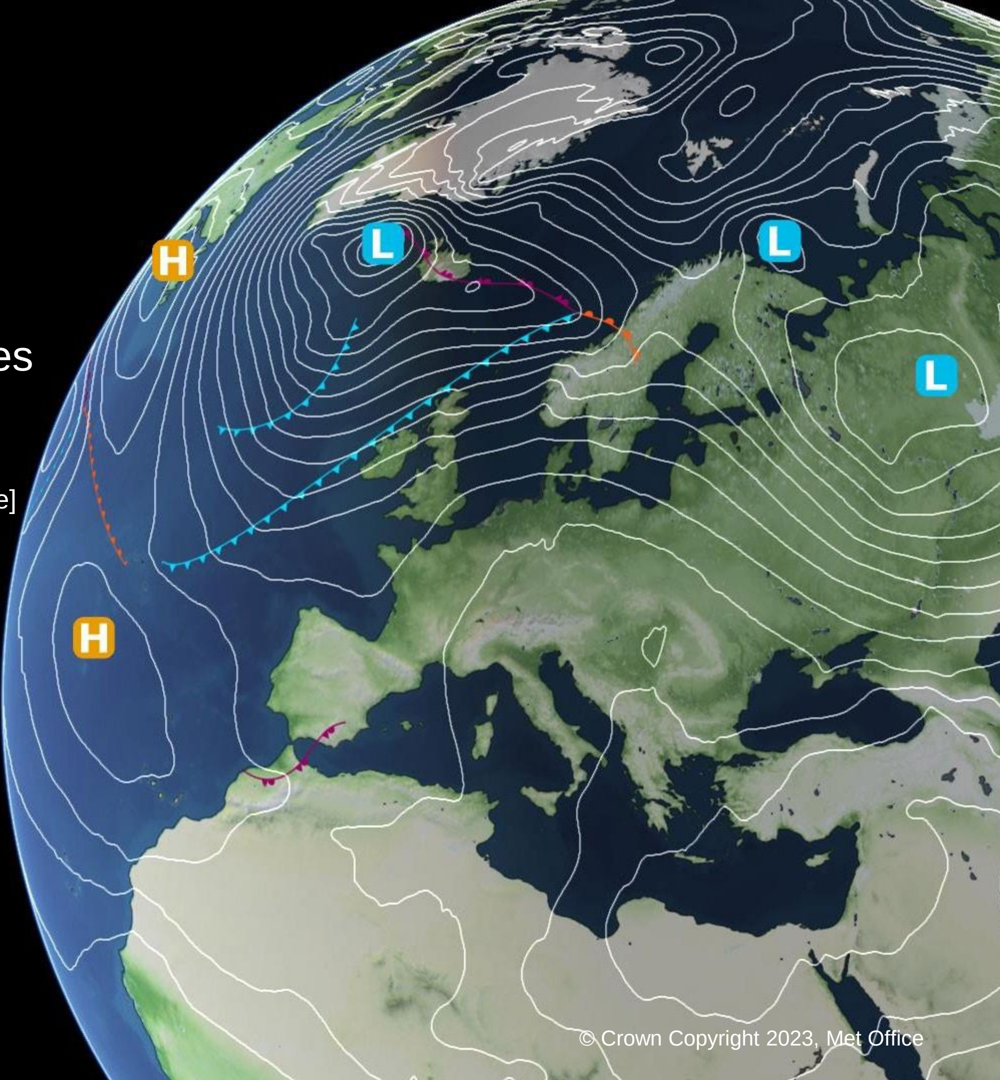
ESA A-TSCV workshop, Toulouse
13th June 2023



Contents

- Motivation
- Overview of the A-TSCV project
- Design of the experiments

Total surface current velocities (TSCV) is defined as the Lagrangian mean velocity at the instantaneous sea surface, corresponding to an effective mass transport velocity at the surface (Marié et al., 2020).

Motivation – users of information about surface currents

The surface current forecasts from ***operational ocean forecasting*** systems provide input to:

- search and rescue operations;
- modelling of oil spill trajectories;
- ship navigation makes use of surface currents to improve the routing of ships;
- the offshore industry makes use of surface currents when towing out heavy production platforms, evacuation of offshore facilities as well as routine maintenance operations;

Surface currents are also important in the context of ***weather forecasting*** since operational NWP systems are now using coupled ocean/atmosphere/sea-ice/wave models.

Motivation – observations and forecasting

Present observation network does not provide global observations of surface currents.

- Surface drifters provide sparse information about ~15 m depth currents (undrogued drifters are even sparser).
- HF radar provides information around some coasts.
- ADCPs are available in very few locations.

Products are available which routinely estimate TSCV:

1. Operational ocean and coupled forecasting systems which combine numerical models (which include most of the processes which govern the evolution of TSCV) with a range of observing systems through data assimilation.
2. Derived products such as from ESA WOC, GlobCurrent and OSCAR.

The lack of global measurements of TSCV means that:

- Operational global ocean forecasting systems do not currently assimilate surface velocity data.
- It is hard to know the accuracy of TSCV from these forecasting systems (most verification is done using surface drifters which don’t tell us the accuracy of the TSCV).

Overall aims of the A-TSCV project

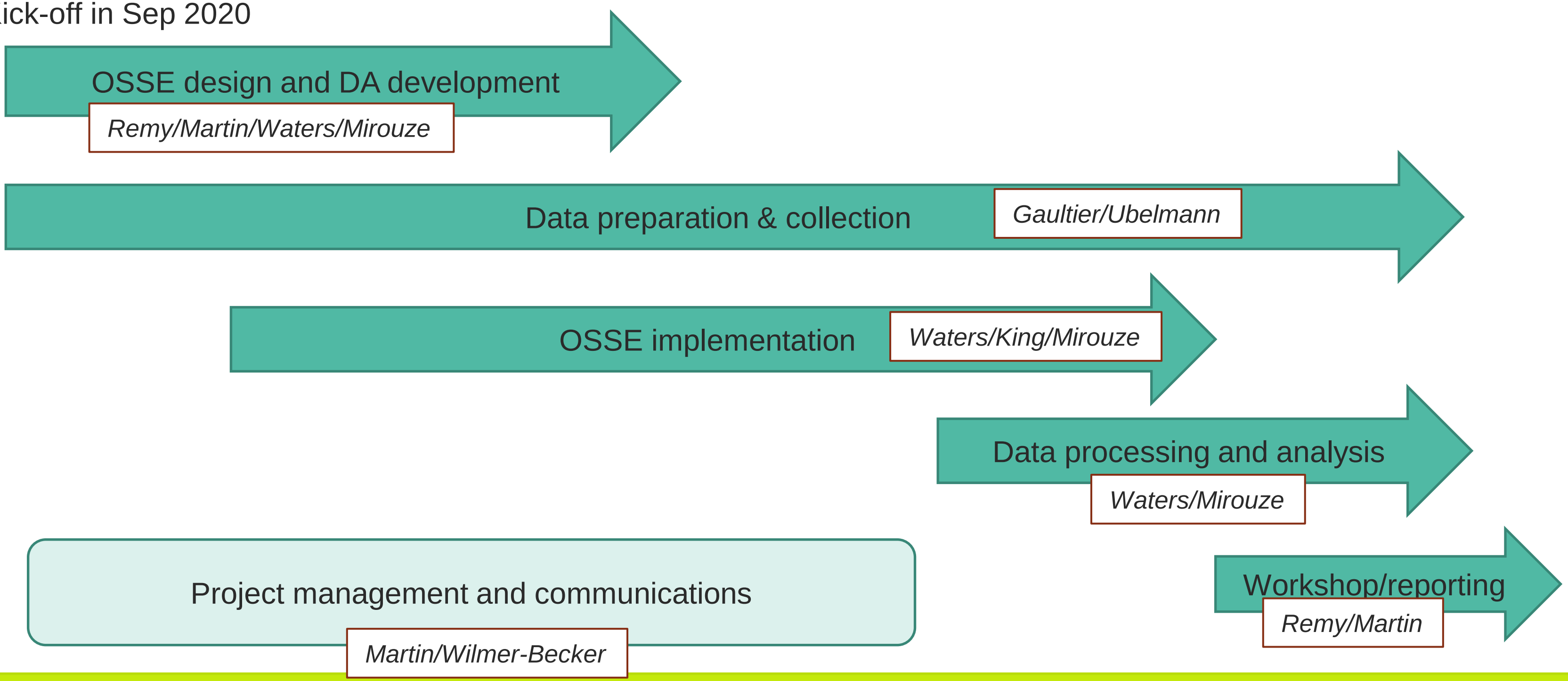
- Various satellite missions have been proposed to measure TSCV including SKIM, SEASTAR, Harmony, ODYSEA. We'll hear about these later today.
- The overall aim of this project is to develop requirements from the international ocean data assimilation and forecasting community for such missions.
- The main objectives are to:

    1. Assess, implement and test methods for assimilating TSCV measurements in global ocean data assimilation systems (in the Met Office and Mercator Ocean systems).
    2. Design, implement and perform a coordinated Observing System Simulation Experiment (OSSE) to test the impact of satellite derived TSCV data on ocean data assimilation and forecasting systems.
    3. Assess the results of the OSSEs.
    4. Refine the requirements for TSCV measurements, based on the results of the OSSE, and provide feedback to the operational forecasting and research communities through various routes including an Observation Impact Statement Report, peer-reviewed journal articles, a website, and the organisation of an international workshop.

Structure of the ESA A-TSCV project

https://oceanpredict.org/science/projects/a-tscv

Kick-off in Sep 2020



OSSE design and DA development

Remy/Martin/Waters/Mirouze

Data preparation & collection

Gaultier/Ubelmann

OSSE implementation

Waters/King/Mirouze

Data processing and analysis

Waters/Mirouze

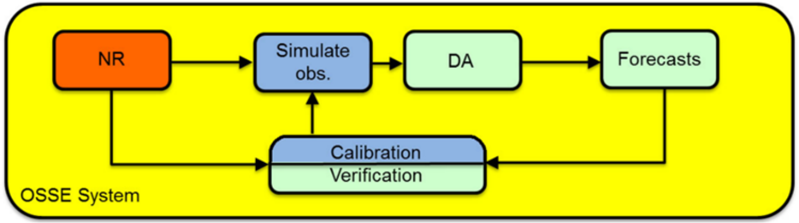
Project management and communications

Martin/Wilmer-Becker

Workshop/reporting

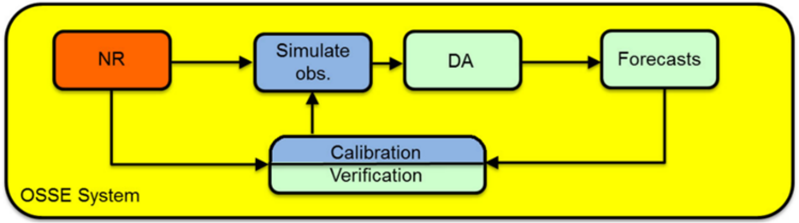
Remy/Martin

OSSE overview



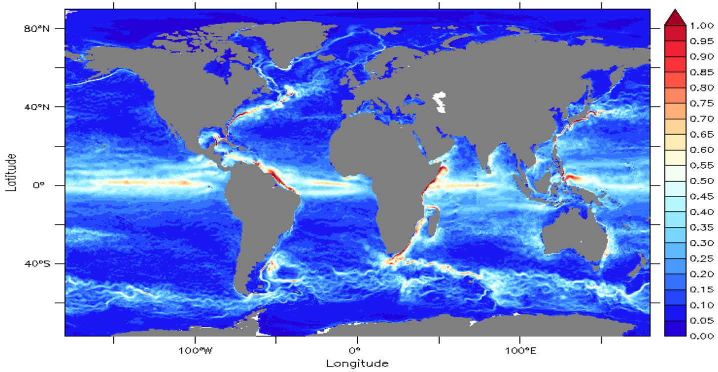
- Observing System Simulation Experiments (OSSEs) provide a way of assessing the impact of future observing systems on data assimilative systems.
- Pseudo observations are extracted from a model simulation, called the Nature Run:
  - Observations are simulated for the standard observing systems available today (e.g. altimeters, T/S profiles, SST, sea-ice concentration).
  - Observations of future missions for TSCV are also simulated.
- The standard observations are assimilated in a control experiment with a different model, different surface forcing and different initial conditions compared to the Nature Run.
- The standard observations + the new TSCV observations are assimilated in an OSSE.
- The analysis obtained after their assimilation can be compared to the full 3D Nature Run model fields and the errors compared with the control simulation to understand the impact the TSCV observations would have in the context of the other existing observing systems, i.e. what do the TSCV data bring in addition the other existing data.

OSSE design

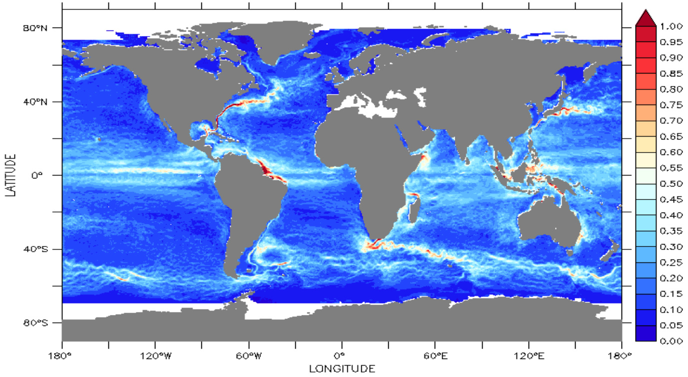


Nature run (NR)

- Free-running nature run is used as the “truth” for generating observations and for assessing results.
- Initially we planned to use a MITgcm high resolution run but had issues (related to high frequency processes, particularly tides) which are described on the project web-site.
- Instead we decided to use a 1/12° free running (no DA) NEMO simulation run by MOI (Gasparin et al., 2018).
- A run of the WaveWatchIII wave model was also carried out (forced by the same atmospheric forcing as the NR)



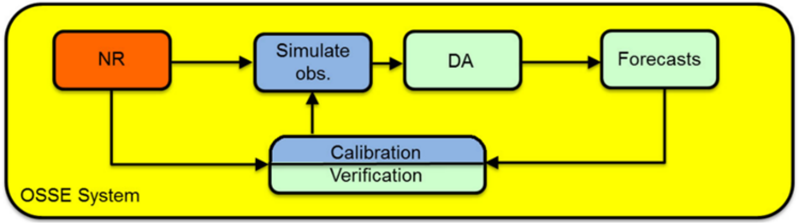
Simulated by the Nature Run at 1/12°



Estimated by GlobCurrent

Mean intensity of surface currents in 2009

OSSE design



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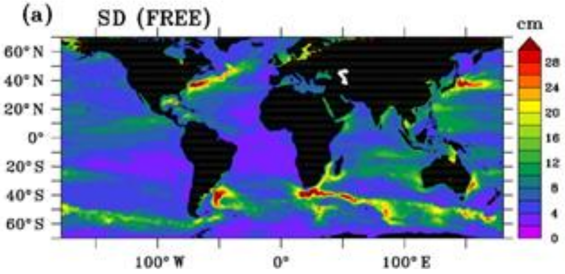
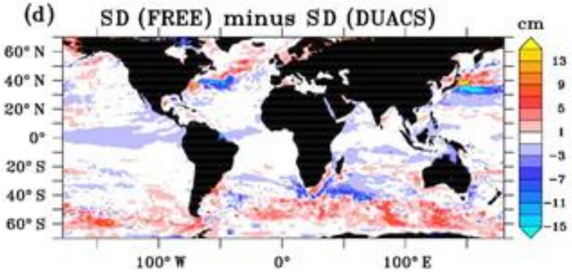
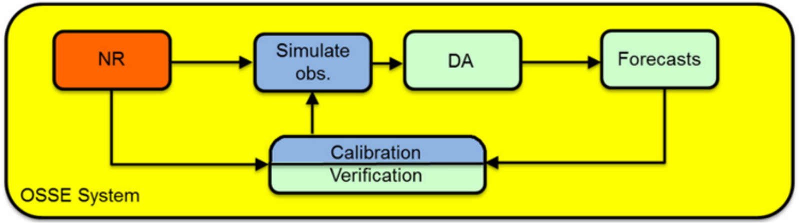


2007–2015 SSH standard deviation of the Nature Run



Difference of the SSH model standard deviation from the DUACS gridded product (blue => NR has less variability than obs)

OSSE design

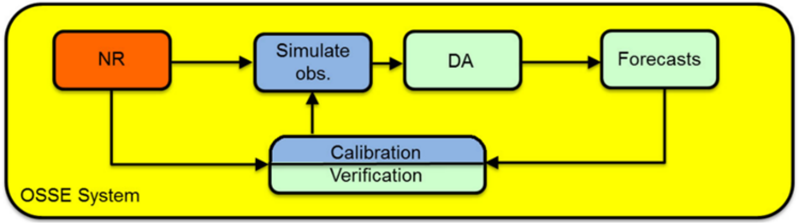


Simulated observations

- Standard observations (SST, SLA, T/S profiles, SIC) were generated as part of the AtlantOS project described in Gasparin et al., 2019 and Mao et al., 2020.
- TSCV observations and their errors were simulated using the SKIMULATOR – see Lucile Gaultier's talk.
- L2-C TSCV data were used for assimilation. These are data along the swath which have been converted into the eastward/northward components of the velocity using an OI technique.

	Mercator Ocean	**Met Office**
In situ T/S profiles	Argo, tropical moorings, drifters and XBT	Argo, tropical moorings, drifters and XBT
Altimetry	S3-A, S3-B, CryoSat and AltiKa	S3-A, S3-B, CryoSat and AltiKa
Sea ice concentration	-	L3 SSMI/S
TSCV	L2-C	L2-C
SST	L4 (OSTIA like maps)	L2

OSSE design

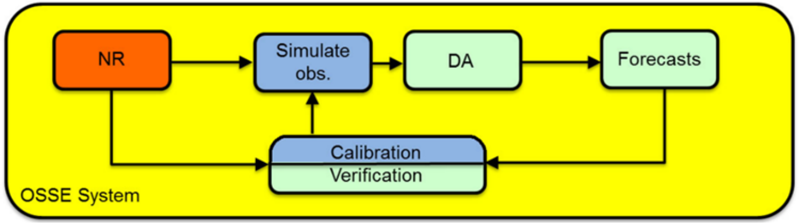


Data assimilation

- Developments to the existing DA systems at Met Office and Mercator Ocean were carried out to assimilate TSCV data – described in Jennie Waters and Isabelle Mirouze presentations.
- Observation operators were developed to transform model fields into equivalents of the TSCV observations.
- Idealised widely-spaced observations were used to check the TSCV assimilation worked correctly and to compare the MetO and MOI results – see web-site for more information.

	Mercator Ocean	**Met Office**
Data Assimilation Scheme	SEEK filter with a fixed basis with 7-day time window	NEMOVAR 3DVar-FGAT scheme with 1-day time window.
Forecast error covariances	Based on an ensemble of model anomalies from an historic model run.	Statistical and parametrised estimates.
Multi-variate relationships	Model covariance matrix based on a reduced basis of multivariate model anomalies.	Linearised physical balances.
Implementation of increments	IAU over 7 days.	IAU over one day.

OSSE design



NR

Simulate obs.

DA

Forecasts

Calibration

Verification

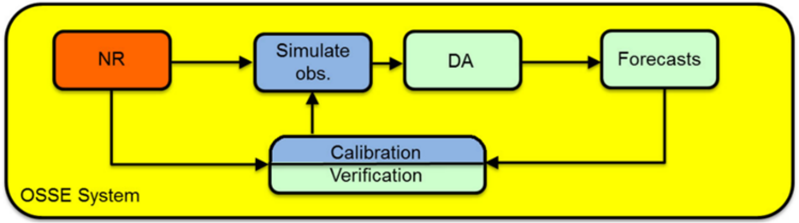
OSSE System

Model set-ups used in OSSEs

- OSSE runs were carried out using lower resolution (1/4°) assimilative systems at MOI and Met Office.
- Different versions of the model were used compared to the NR.
- Different surface forcing used in NR and OSSEs (operational ECMWF vs ERA5).

	Nature Run	Mercator Ocean	Met Office
OGCM	NEMO 3.1	NEMO 3.6	NEMO 3.6
Horizontal grid/resolution	1/12° ORCA grid	¼° ORCA grid	¼° ORCA grid
Vertical grid	50 levels	50 z-levels with partial steps, linear free surface	75 z-levels with partial steps, non-linear free surface
Wind/current coupling coefficient	50%	50%	100%
Ice model	LIM	LIM3	CICE
Atmospheric forcing	ECMWF IFS	ERA5	ERA5

OSSE design



OSSEs carried out

- Experiments run for 21st Jan – 31st Dec 2009.

Experiment	**Assim SST**	**Assim T/S profiles**	**Assim SSH**	**Assim SIC[1]**	**Assim TSCV**	**TSCV Errors**
Control	✓	✓	✓	✓	×	-
A-TSCV no_err	✓	✓	✓	✓	✓	Mapping only
A-TSCV instr_err	✓	✓	✓	✓	✓	Mapping error + Instrument error

Assessment methodology

- Compare OSSE fields to the Nature Run – advantage of OSSEs is that we know the “true” state everywhere.
    - Impact on statistics of the errors in the modelled surface currents with and without TSCV assimilation in different regions.
    - Impact of TSCV assimilation on errors in the sub-surface currents.
    - Impact of TSCV assimilation on other variables, e.g. temperature, salinity, SSH.
    - Impact in the analysis and in 7-day forecasts.
- Lagrangian particle tracking assessments:
    - Using the OceanParcels package to understand the impact of assimilating TSCV data on the accuracy of forecasts of particles in the ocean.
- Assessing the representation of near-inertial oscillations using power spectrum methods.

=> Descriptions of the DA set-up and results will be presented by Jennie Waters and Isabelle Mirouze.

Requirements

Final part of the project is to define the requirements from the operational ocean forecasting community for future satellite TSCV missions including:

- Accuracy;
- Horizontal resolution;
- Temporal resolution (frequency);
- Important regions;
- Timeliness;
- Need for estimates of the uncertainties: random uncorrelated, random correlated, bias.

We encourage inputs on these requirements in the discussion later today.

Additional work funded through A-TSCV project

- ESA requested that we run some additional OSSEs to study the potential impact of different swath altimetry and nadir altimetry constellation configurations.
- We assessed the impact of two different options for the Sentinel-3 Next Generation (S3-NG) altimeter constellation on MetO and MOI systems:
    1. A 2 wide-swath altimeter constellation.
    2. A 12 nadir altimeter constellation.
- Relevant for this workshop since:
    - the altimeter constellation has a major bearing on the baseline system available for estimating the geostrophic component of the currents in the future.
    - It highlights that the impact of observations is very system-dependent – we got very different results from the MetO and MOI systems in this study.
- Rob King will briefly present results from this study (from MetO and MOI systems).

Overview of agenda for the workshop

09:45 – 11:45. Presentations on the work of the A-TSCV project.

11:45 – 15:35. Presentations on other work related to assimilating surface current data.

15:35 - 16:15. Presentations on mission concepts to measure TSCV.

16:45 – 17:45. Discussions:

1. Assimilation of surface velocity data: lessons learnt and challenges.
2. Expected benefits and requirements for velocity observations from space, for operational oceanography.

Breaks:

- Coffee breaks at 10:35 – 11:05 and 16:15 – 16:45
- Lunch break at 12:10 – 14:00

Thank you

Definitions - TSCV

Total surface current velocities (TSCV):

- Marié et al. (2020): TSCV is defined as the Lagrangian mean velocity at the instantaneous sea surface, corresponding to an effective mass transport velocity at the surface.
- ESA (2019): TSCV is defined as the velocity of a water parcel in contact with the atmosphere at any given location and time.

The TSCV is the result of a combination of different forces including:

1. Frictional stress of the wind acting on the sea surface.
2. Ocean surface wave-induced inertia and pressure gradient, leading to Stokes drift.
3. Coriolis force related to the Earth's rotation.
4. Large scale (>10 km) pressure gradients due to variations in surface elevation (gravitation, including tides, atmospheric pressure, local topography) and to variations in density, including the effects of stratification.

The average velocity of particles at the ocean surface is described by the sum of various terms including:

1. Geostrophic currents arising from the pressure gradients.
2. Ekman, or mean wind-driven, component.
3. Wave-induced Stokes drift
4. Tides
5. Near-inertial oscillations driven largely by variable wind-stress.

Agenda for the workshop

Time (UTC + 2)	Presenter and affiliation	Title of talk (20 min presentation + 5 min Q&A)
9:45 – 10:10	Lucile Gaultier (OceanDataLab)	Satellite observation simulator
10:10 – 10:35	Jennifer Waters (Met Office)	Assimilation of total surface current velocities in the Met Office ocean forecasting system for the ESA A-TSCV project
10:35 – 11:05	**Coffee break**	
11:05 – 11:30	Isabelle Mirouze (freelance consultant, MOI)	The impact of assimilating simulated satellite surface velocities in the Mercator analysis and forecasting global system
11:30 – 11 :45	Robert King (Met Office)	S3NG constellation OSSEs
11:45 – 12:10	Solène Jousset (CLS)	ODYSEA mission project: study of NIO signals in drifter databases and evaluation of multi-temporal mapping of the total current (including NIOs) through OSSE.
12:10 – 14:00	**Lunch break**	Lunch at the pizzeria DiCaprio
14:00 – 14:25	Jaime Hernandez Lasheras (SOCIB)	Comparing High Frequency Radar radial and total derived observations capability to correct surface currents using Data Assimilation
14:25 – 14:50	Sourav Sil (Indian Institute of Technology Bhubaneswar)	High Resolution of Circulation Features along Indian Coast using HF Radar Derive Surface Currents
14:50 - 15:10	Laura Risley (University of Reading)	On the choice of velocity control variables for variational ocean data assimilation.
15:10 – 15:35	Martina Idžanović (MET Norway)	Forecast uncertainty and ensemble spread in surface currents from a regional ocean model
15:35 – 16:00	Odysea Science Team	A satellite mission concept to unravel small-scale ocean dynamics and air-sea interactions: ODYSEA (Ocean Dynamics and Surface Exchange with the Atmosphere)
16:00 – 16:15	Fabrice Collard (OceanDataLab)	TSCV future mission concepts at European Space Agency: a focus on SeaStar and Harmony
16:15 – 16:45	**Coffee break**	
16:45 – 17:15	Discussion: part 1 Moderator: Elisabeth Rémy	DA of surface velocities: observation operator, observation error, model covariance, DA approach (ensemble,4d/3dVar, ”image”,…), lessons learnt from HF radar and surface drifters, challenges…
17:15 – 17h45	Discussion: part 2 Moderator: Matt Martin	Expected benefits and requirements for velocity observations from space, for operational oceanography.