Use of Satellite Data to Support Ocean Wind & Wave Forecasting: A Review

ESA Atlantic from Space Workshop

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Saleh Abdalla(*), Giovanna De Chiara, Jean Bidlot, Lars Isaksen

ECMWF, Shinfield Park, RG2 9AX, UK

(*) Saleh.Abdalla (AT) ECMWF.INT

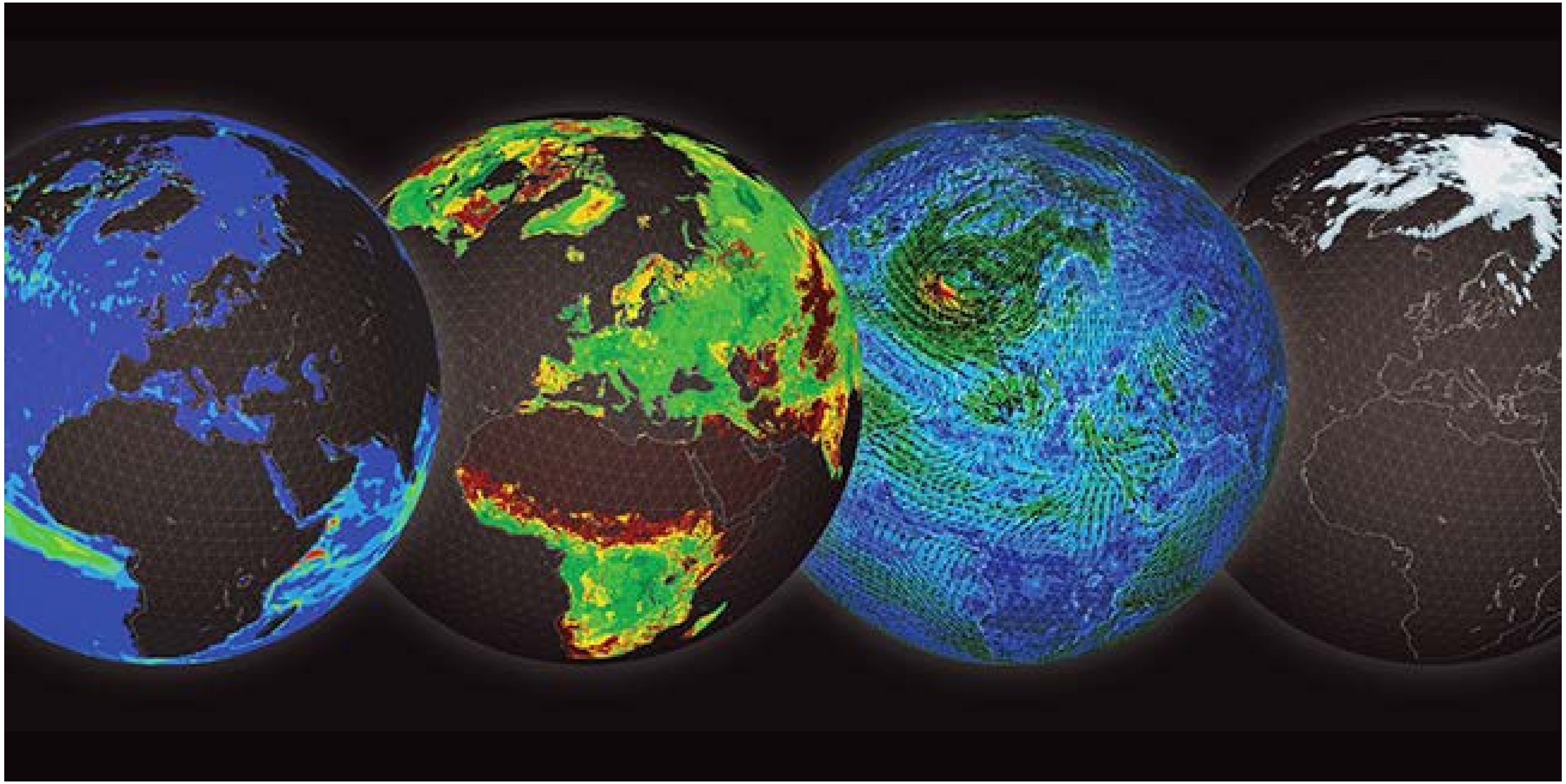
Outline

- “Earth System” approach & coupling.
- Status of ocean wind and wave data (Altimeter), analysis and forecasts.
- Progress in ocean wind & wave forecasts
- Status of ocean surface winds – Scatterometer & SMOS .
- Conclusions in a form of assessment and potential for improvements.

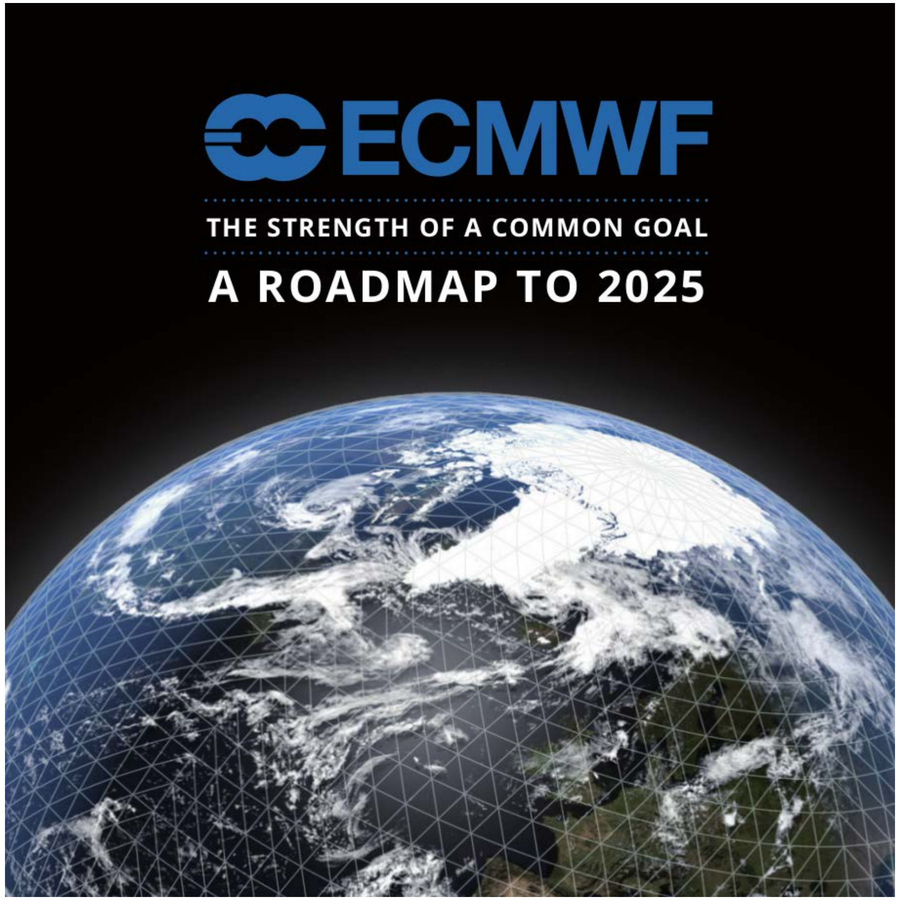
“Earth System” approach.

Coupling.

Uncoupled: Ocean – Land – Atmosphere – Sea ice



“Earth System” Approach



Strategy 2016-2025

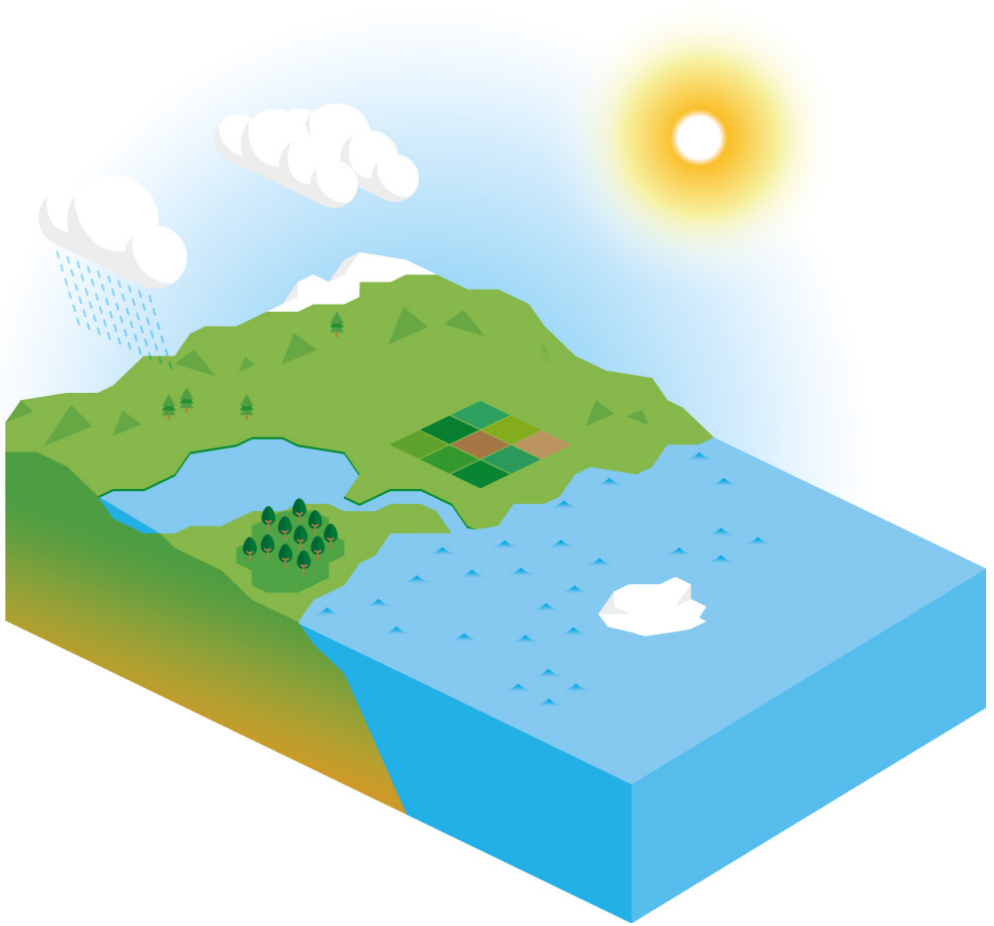
- Coupled modelling of the Earth System Components

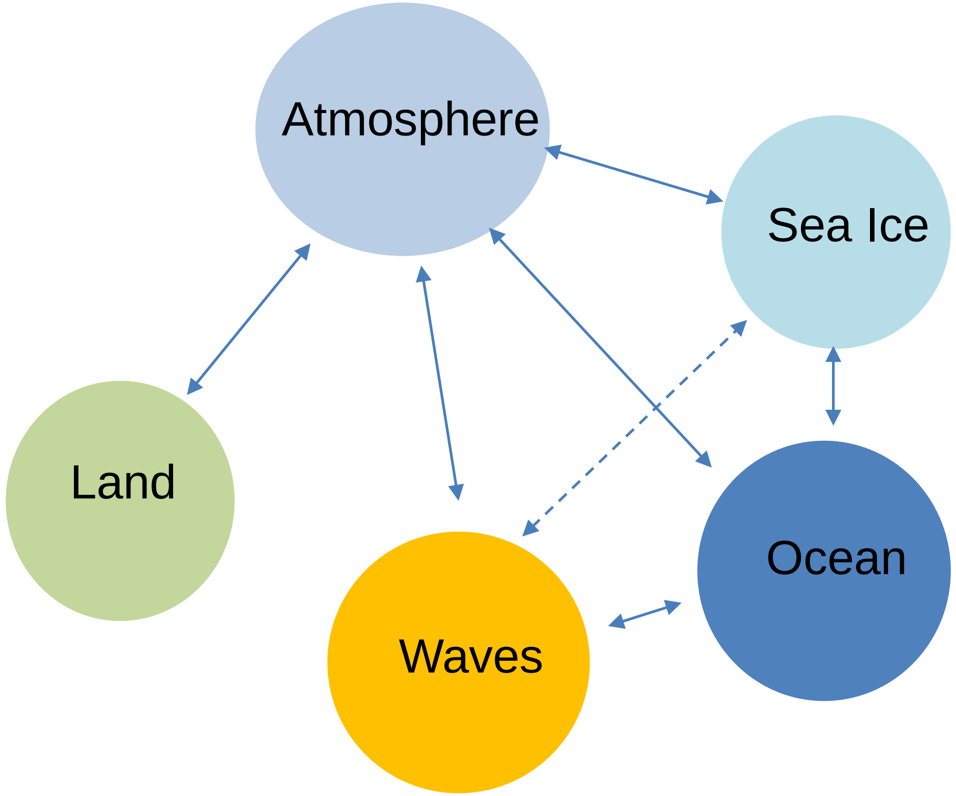
- Interactions between the different components in the model and assimilation

- Coupled assimilation → consistent initial conditions to the coupled model.

Earth System components

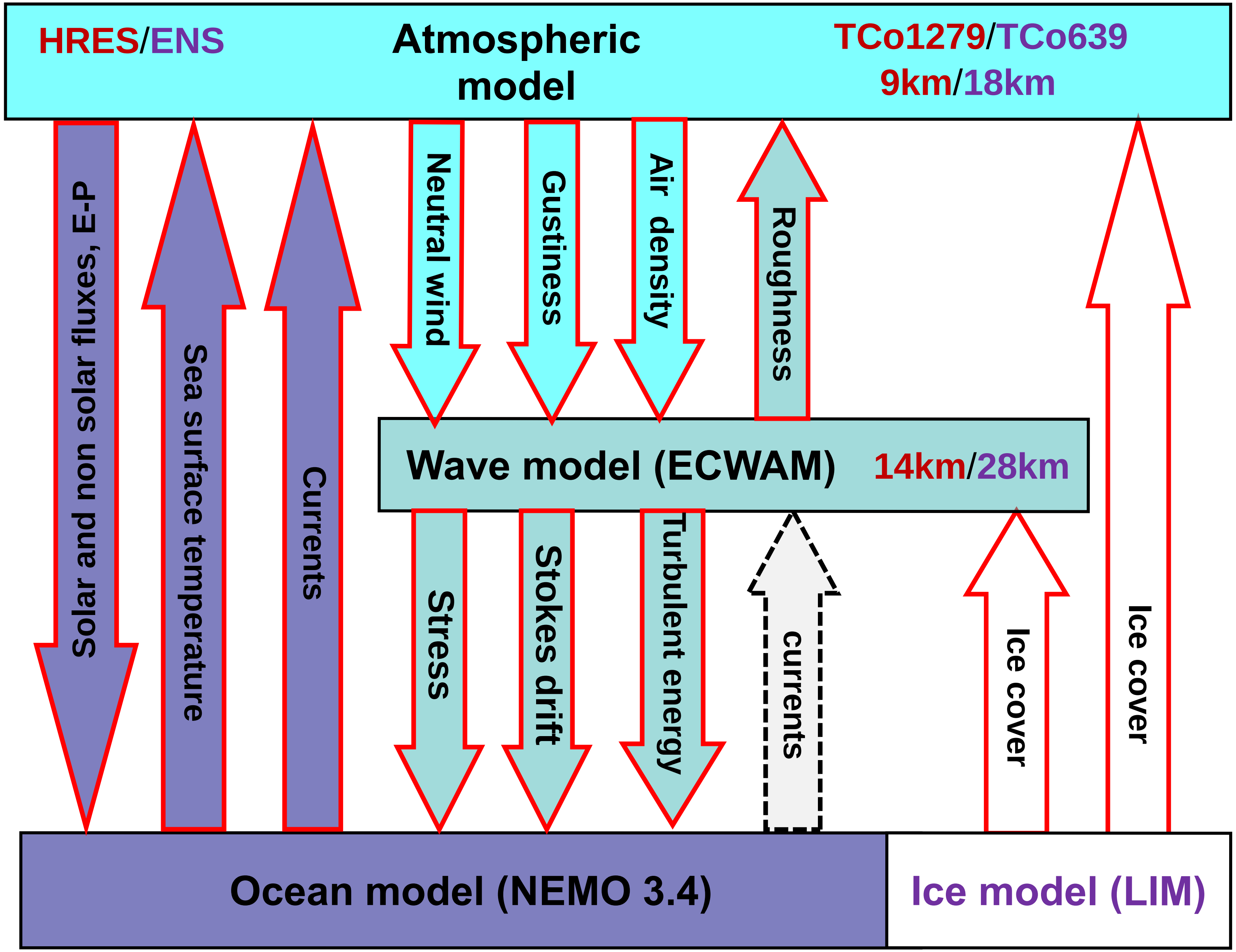
Coupled models within Integrated Forecasting System (IFS)





NWP HRES (since June 2018)
ENS, medium, extended, seasonal
CERA system

ECMWF modeling infrastructure at ocean surface



All configurations

Implementation:
CY46R1
later in 2019.

ORCA025_Z75

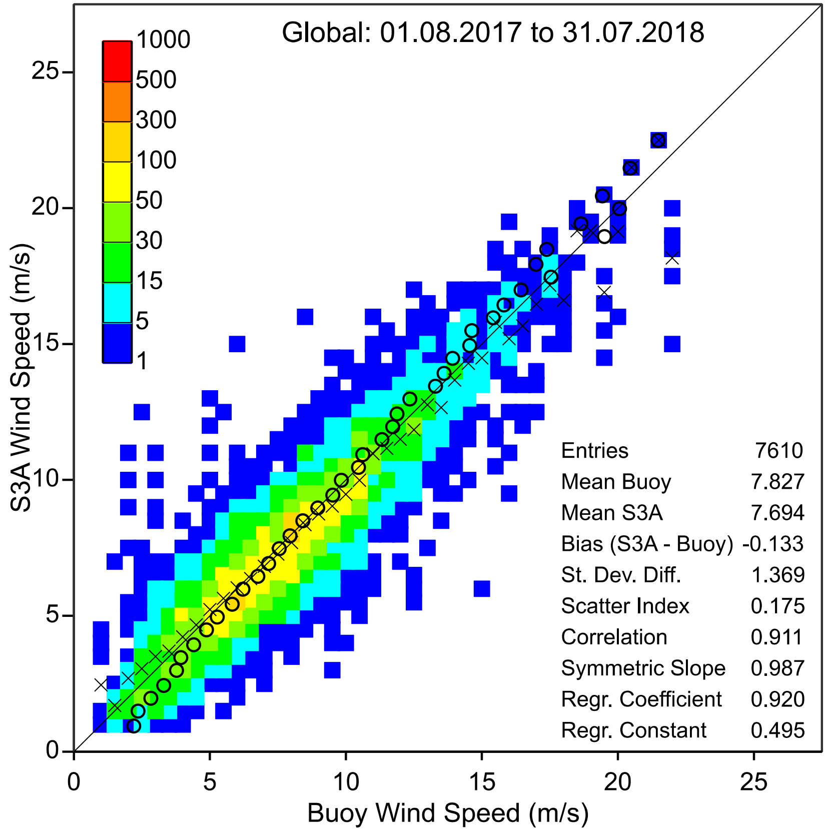
Status of ocean sea-state (mainly altimeter) data, analysis and forecasts

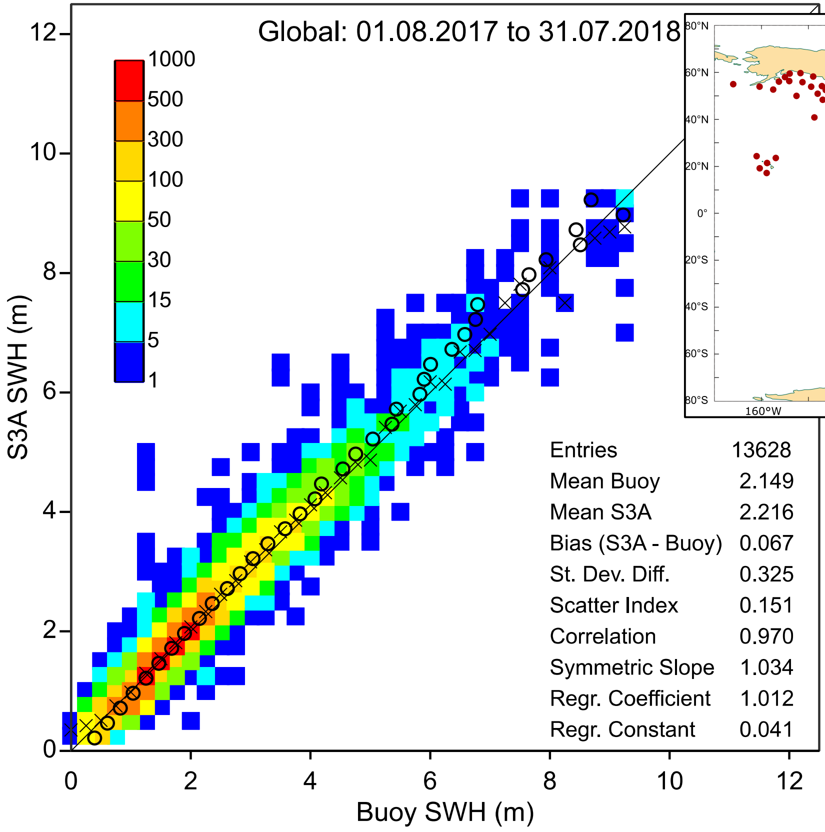
Ocean wind & waves measurements

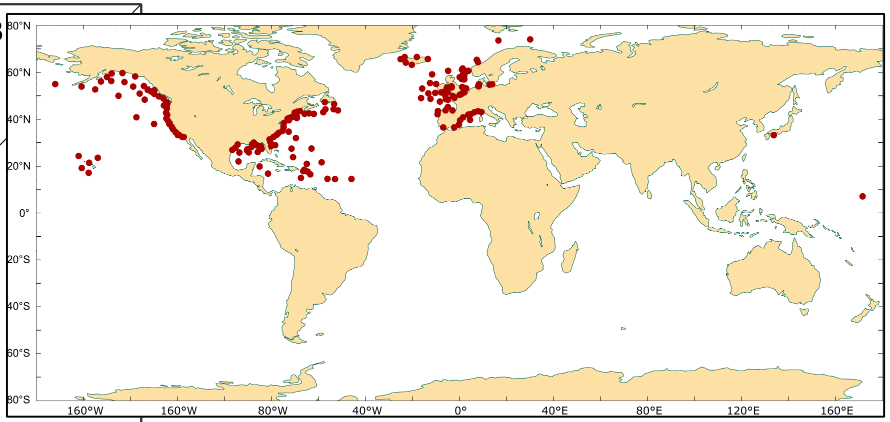
- In-situ:
  - **Buoys**: significant wave height, wave period, wind vector, wave spectrum.
  - **Platforms**: significant wave height, wave period, wind vector.
  - Coastal radars: significant wave height.
  - Others: e.g. Wave parameters from pressure transducers; winds from ***ships***.

- From space:
  - **Altimeters**: Significant wave height (SWH), surface wind speed. (e.g. Sentinel-3 SRAL).
  - ***Synthetic Aperture Radar*** (SAR): wave spectrum (of long waves), surface wind (e.g. Sentinel-1).
  - **Scatterometer** (SCAT): surface wind vector (e.g. MetOps ASCAT).
  - Real Aperture Radar: significant wave height, wave spectrum (CFOSat ***SWIM***).
  - Others: e.g. Wind speed from ***SMOS***.

Altimeter (Sentinel-3A) wind speed & significant wave height comparison against in-situ measurements



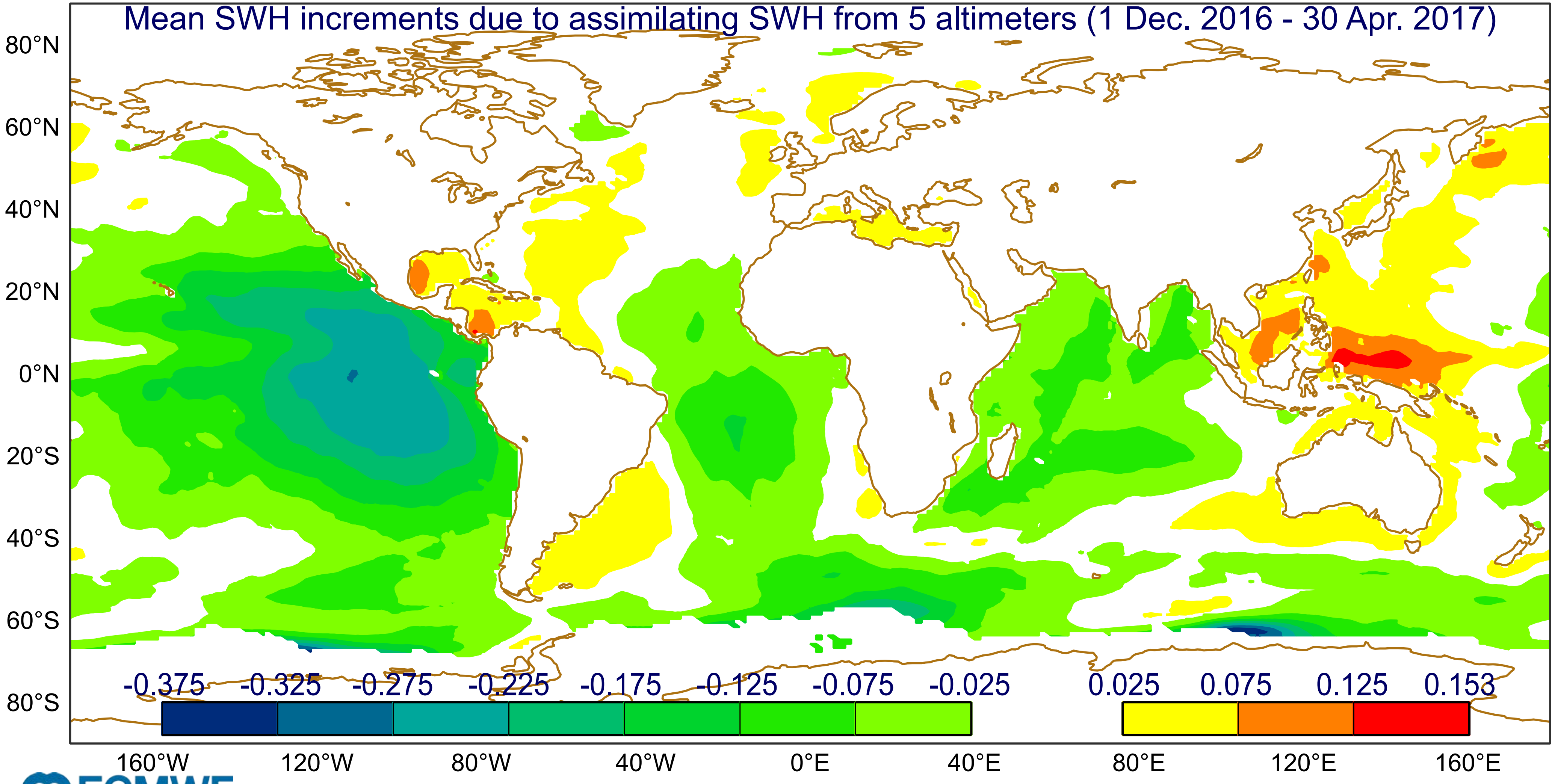




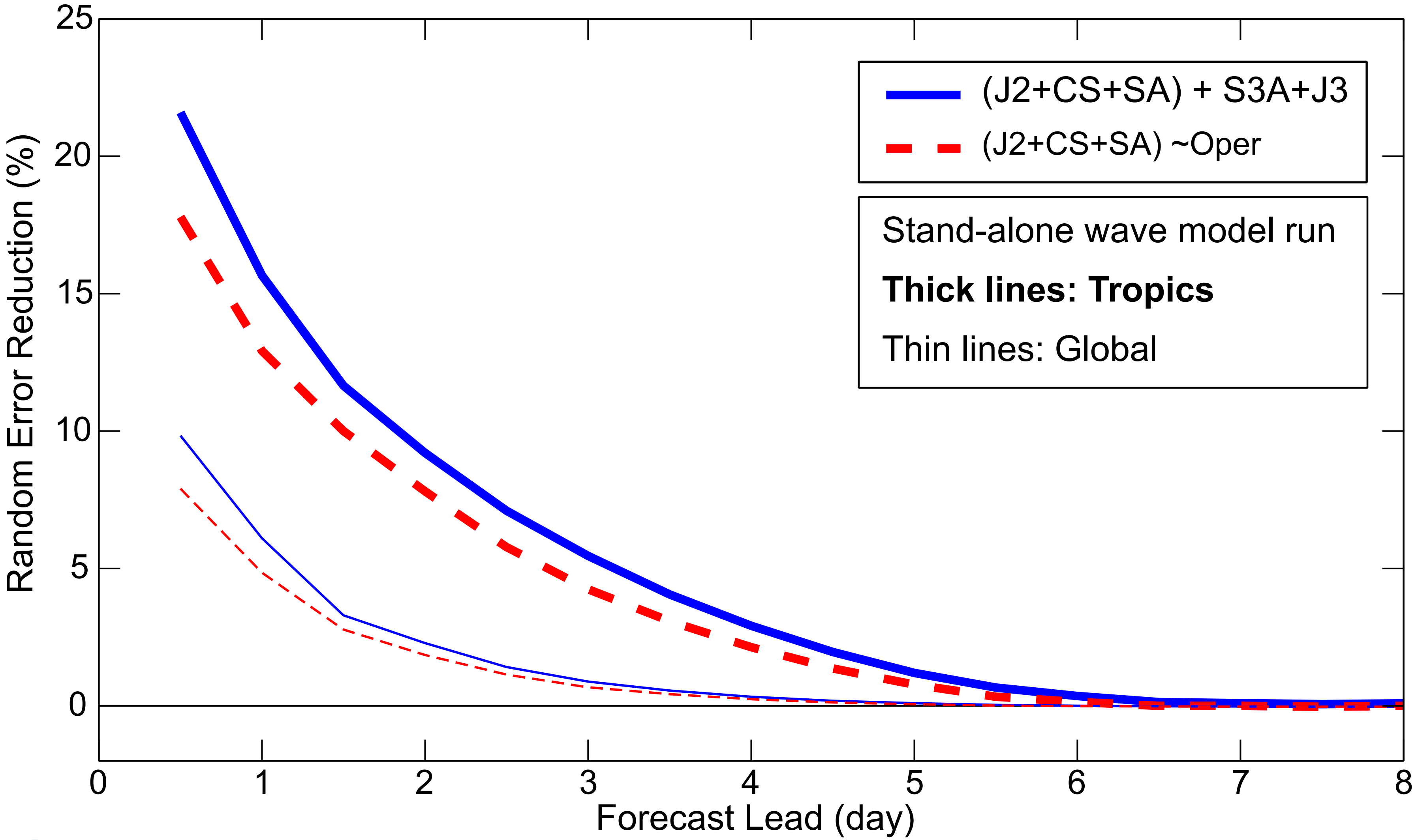
Impact of wave data assimilation (Altimeter SWH)

- ECMWF wave model (ECWAM) which is part of Integrated Forecasting System (IFS).
- Assimilation of SWH at a scale of ~70-80 km (super-observations).
- Based on Optimum Interpolation (OI).
- Control: assimilating Jason-2, CryoSat-2 and SARAL/AltiKa SWH data.
- Impact of adding Jason-3 & Sentinel-3A data:
  – Improvement of model analysis
  – Improvement of model forecast.
  – Improvement of the robustness of the wave data assimilation system.

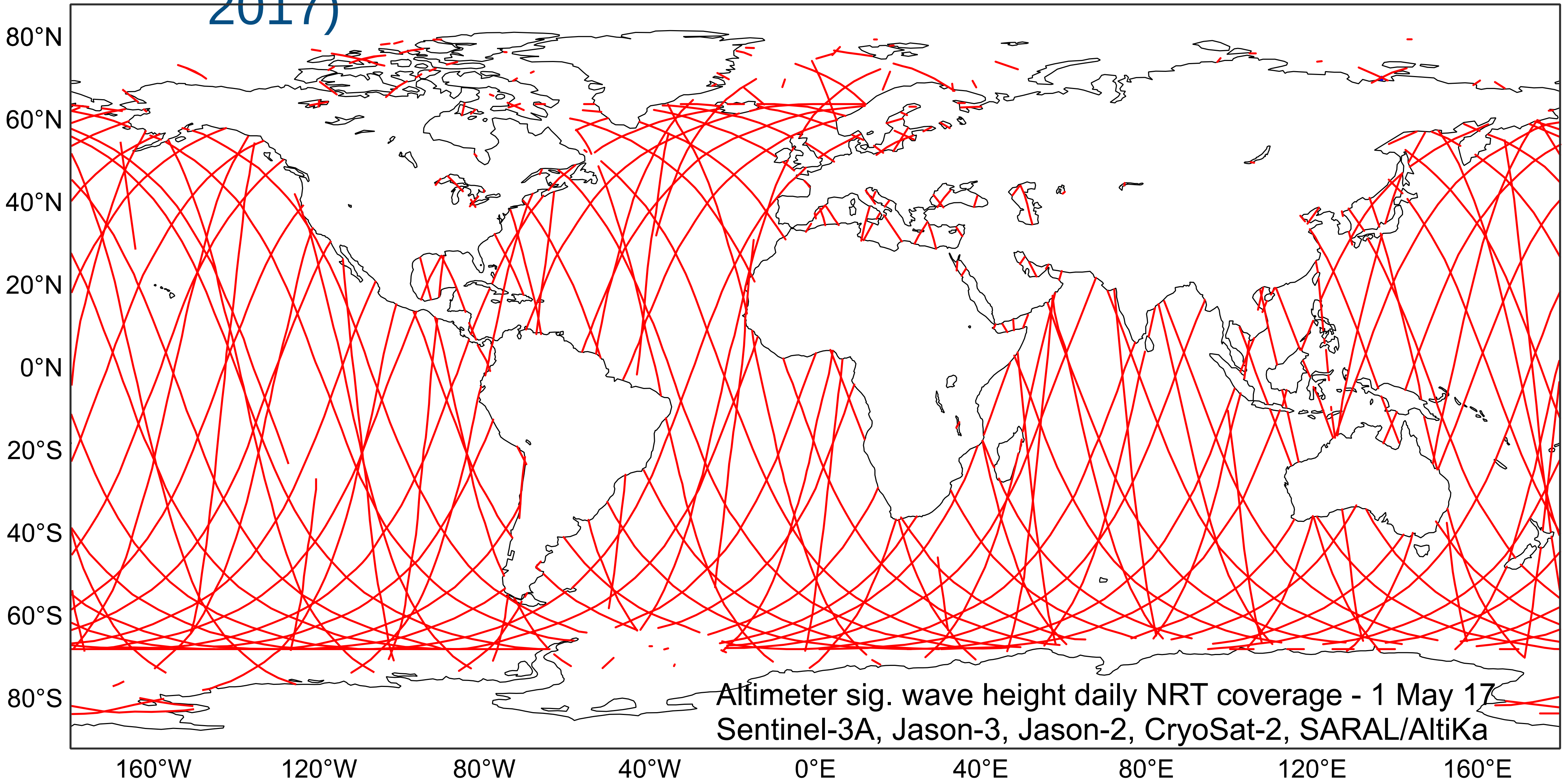
Impact of altimeter SWH data (from 5 altimeters) assimilation on model analysis (1 Dec. 2016 – 30 Apr. 2017)



Impact of altimeter SWH data (from 5 altimeters) assimilation on model forecasts (1 Dec. 2016 – 30 Apr. 2017)

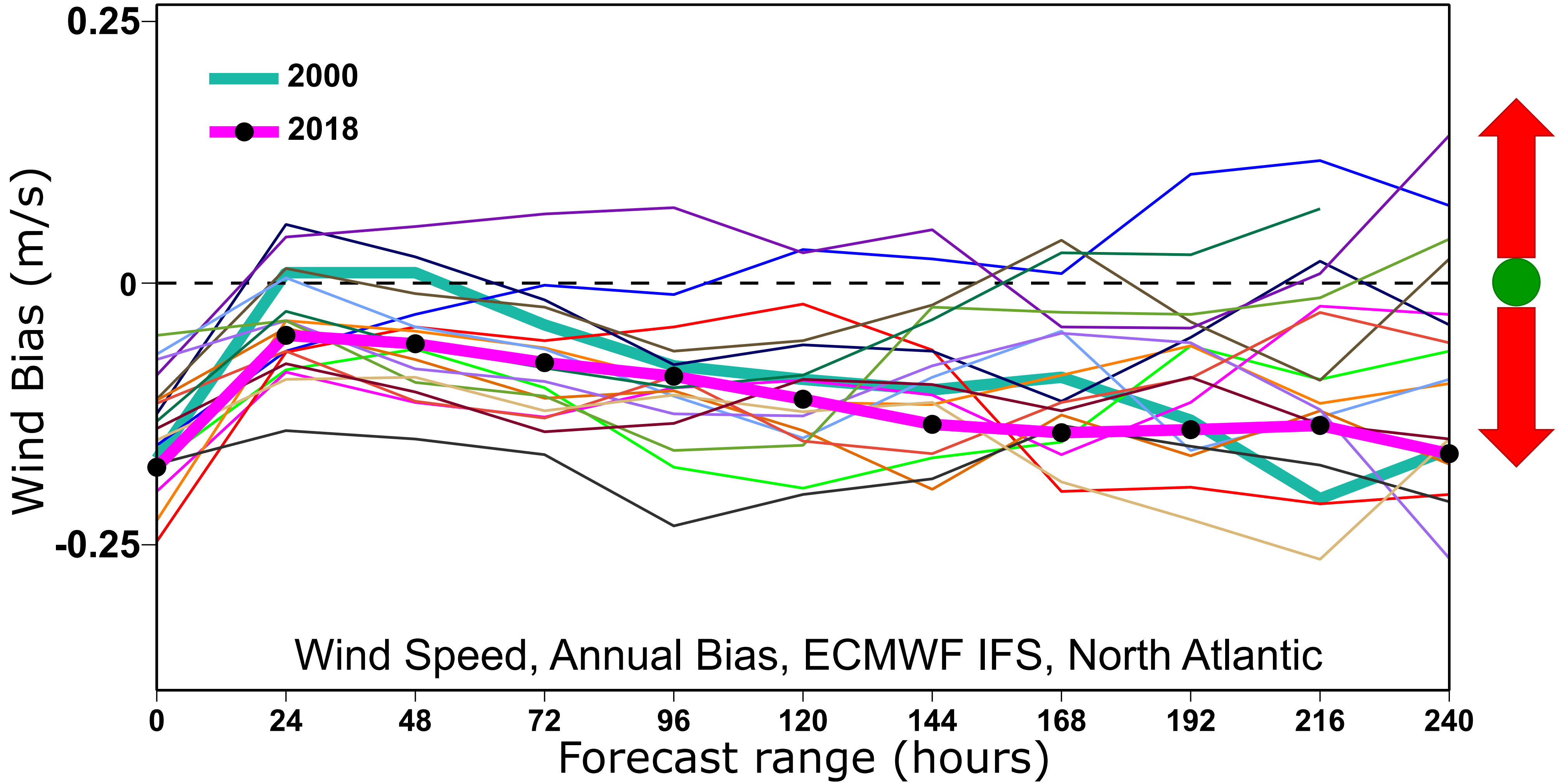


Daily Coverage of NRT Altimeter SWH (1 May 2017)

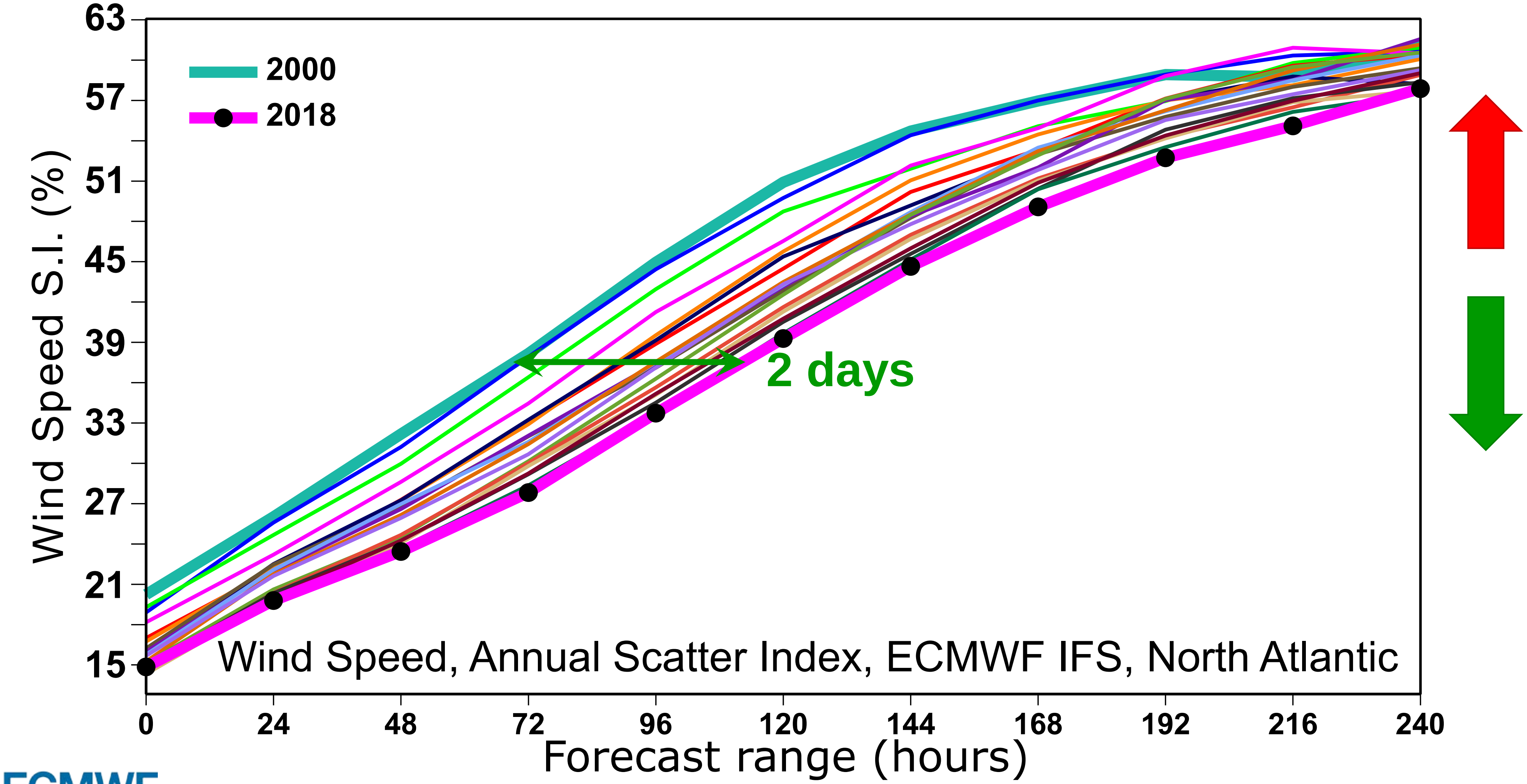


Progress in ocean wind & wave forecasts in the North Atlantic

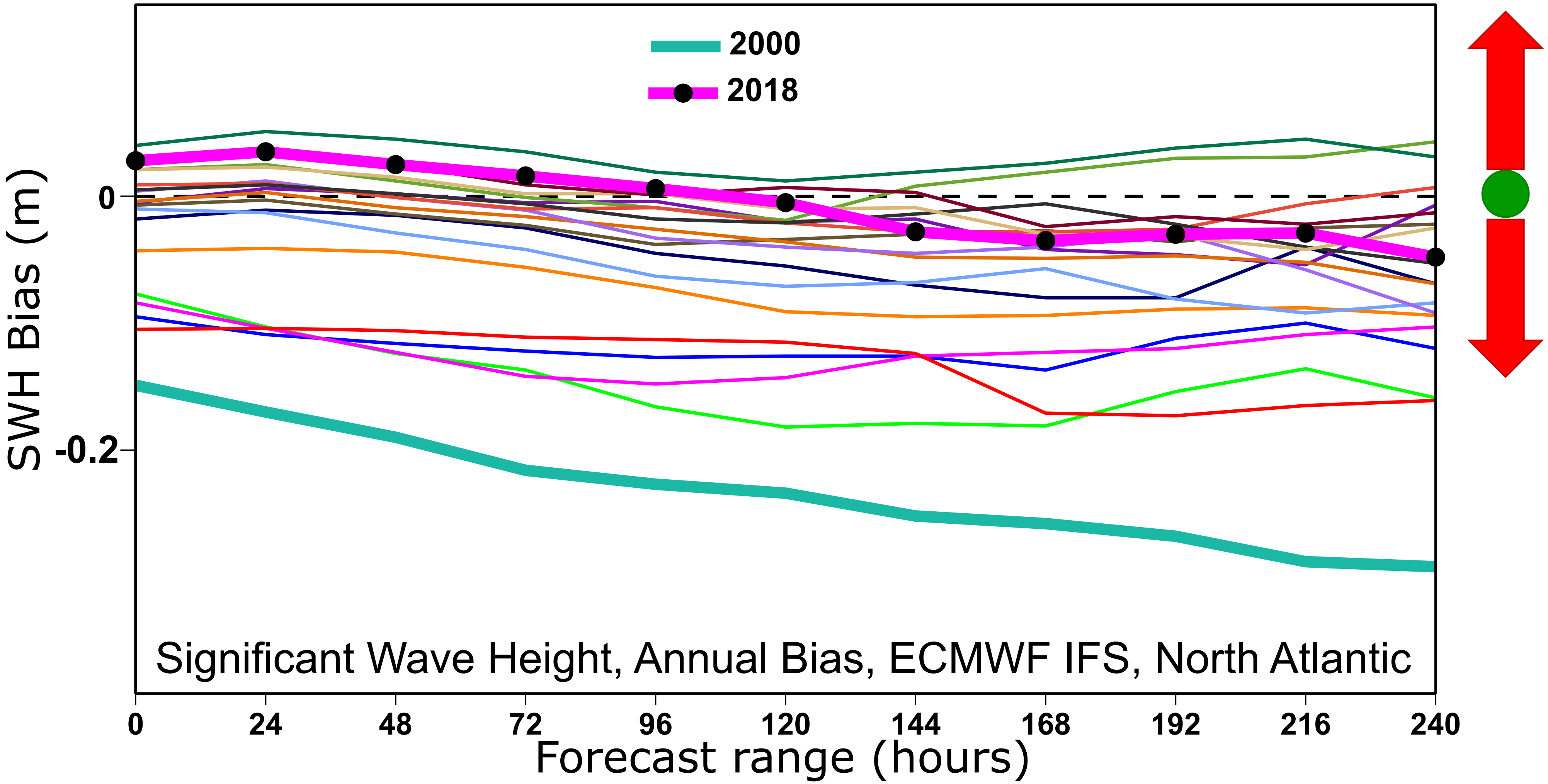
Progress in surface wind speed forecasts since 2000:
1. Bias



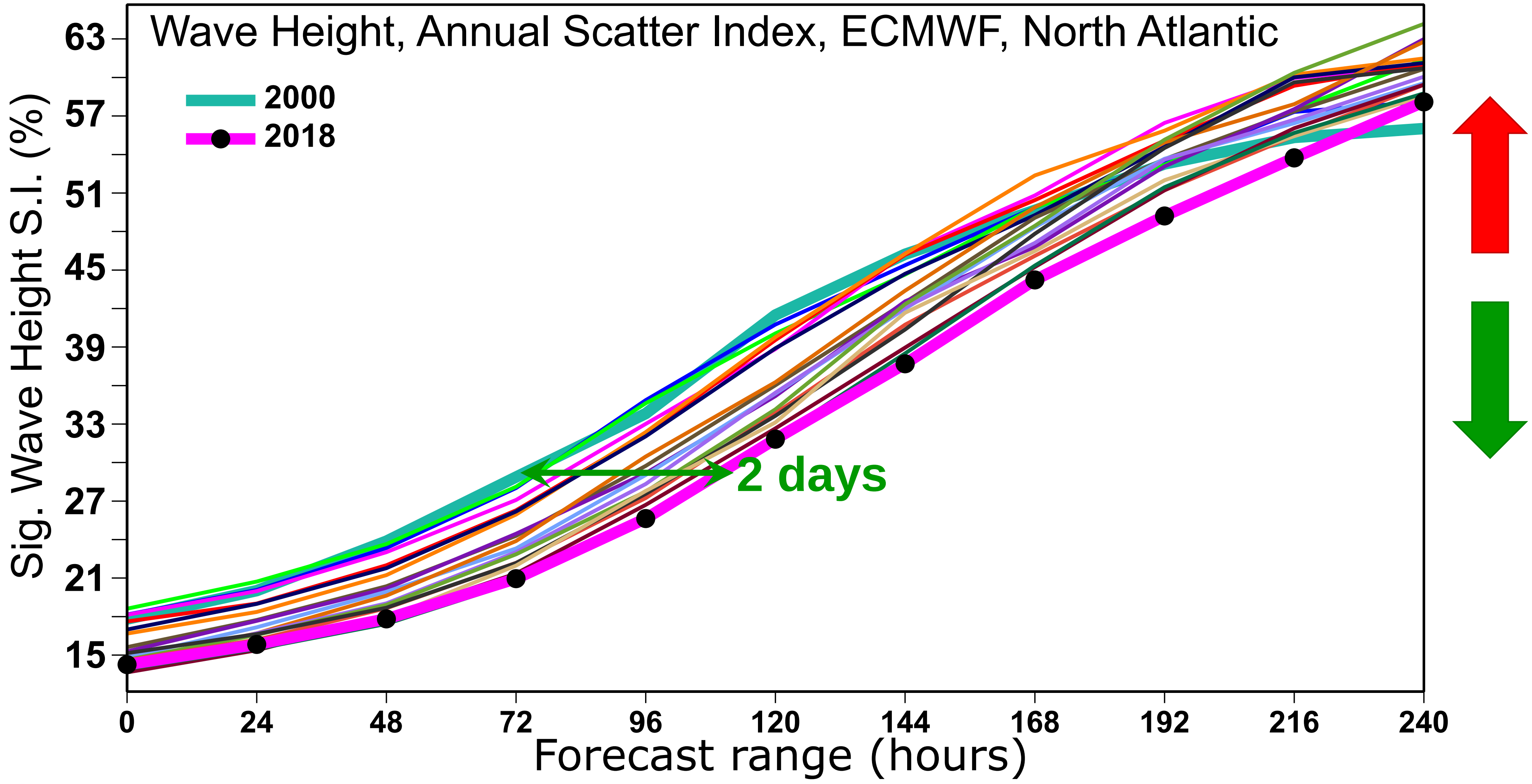
Progress in surface wind speed forecasts since 2000:
2. Random error



Progress in significant wave height forecasts since 2000: 1. Bias



Progress in significant wave height forecasts since 2000:
2. Random error

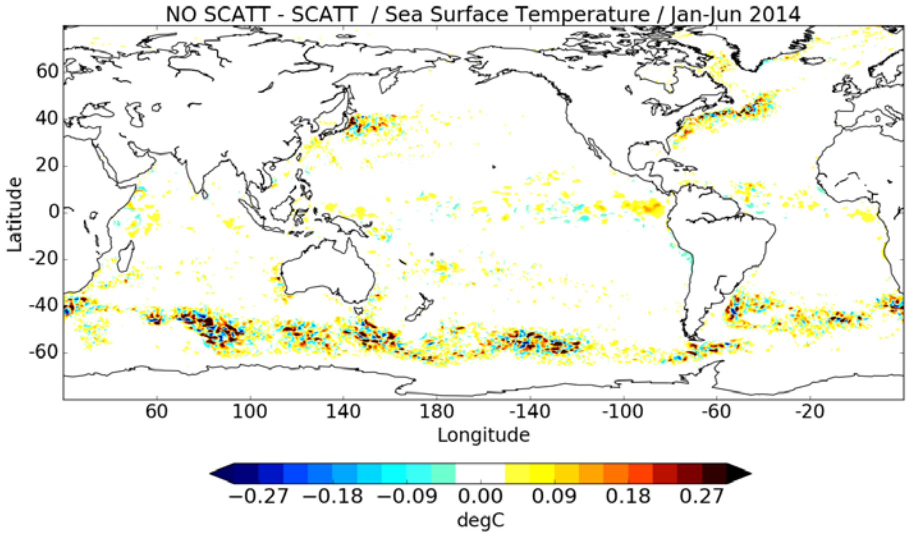


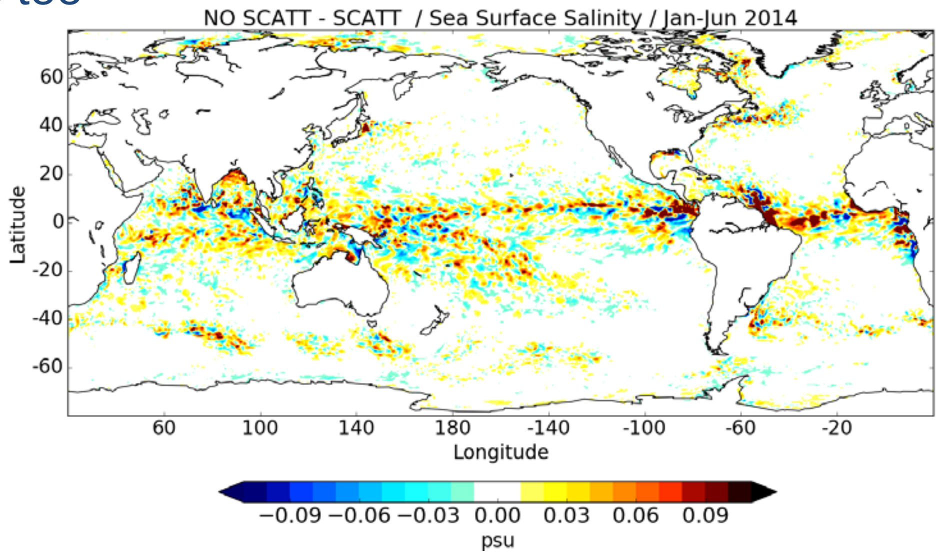
Status of ocean surface winds – Scatterometer & SMOS

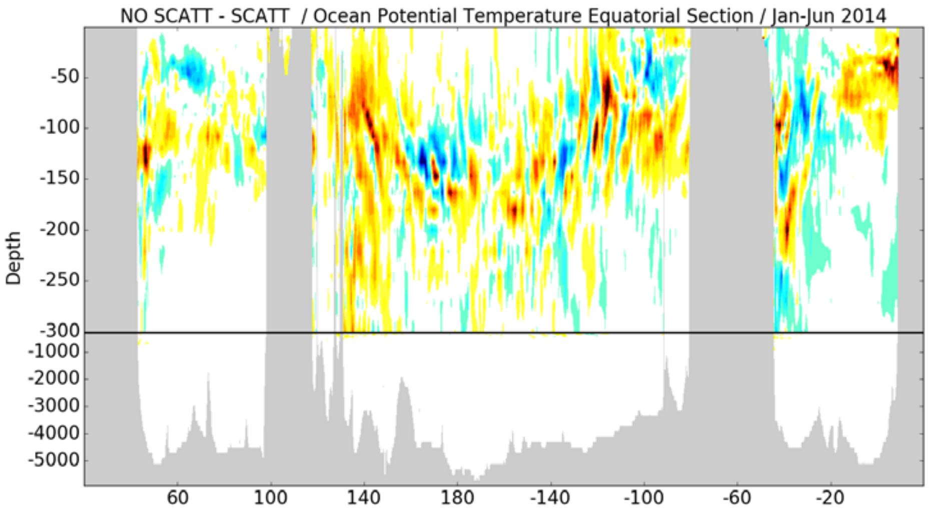
ECMWF

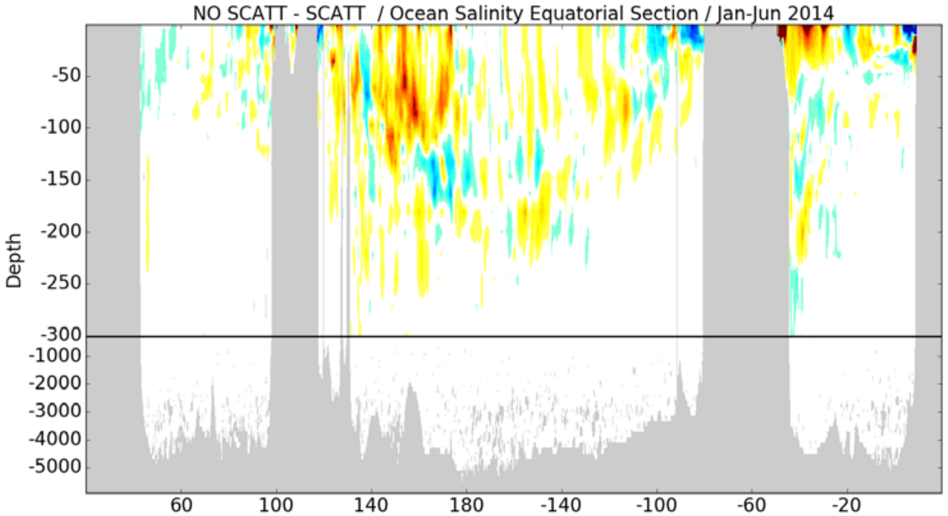
Scatterometer ocean surface vector winds

- ✓ Scatterometer wind vectors are important measurements at the atmosphere/ocean interface
- ✓ They have always known to have an impact on the atmosphere analysis and forecast
- ✓ In a coupled atmosphere/ocean/wave assimilation system it has been proven that Scatterometer winds have an impact on the ocean parameters too



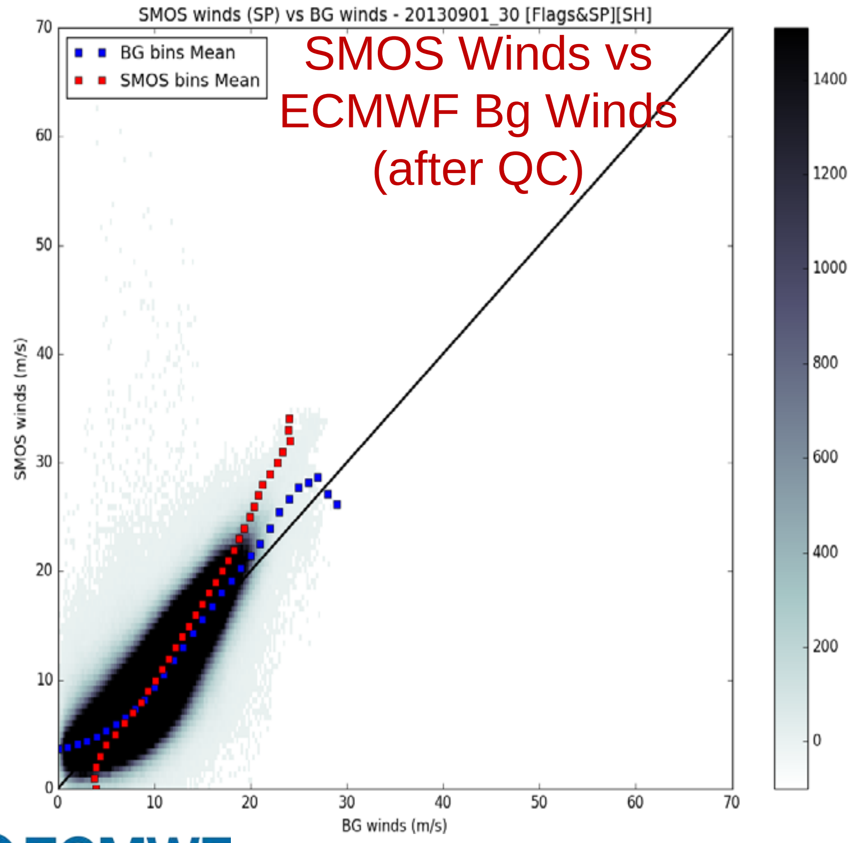


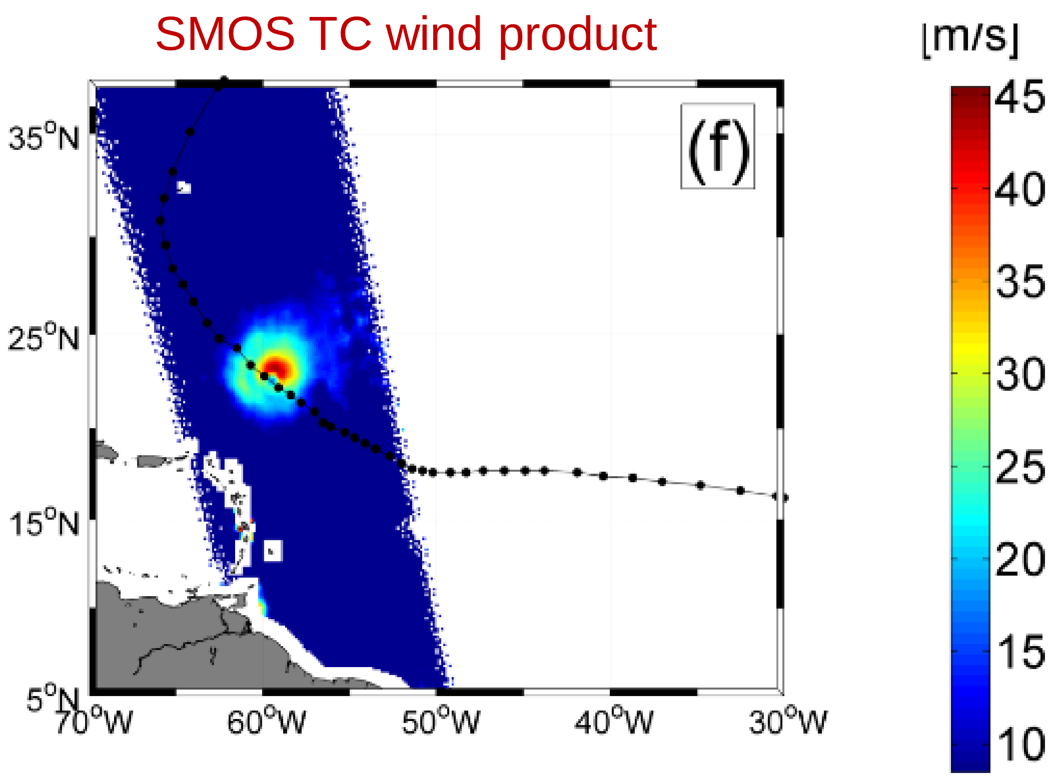




SMOS wind products

- ✓ SMOS mission provides multi-angular L-band brightness temperature (resolution 30/80 km).
- ✓ L-band is less affected by rain, spray and atmospheric effects than higher mw frequencies (C-band, Ku-band). There is no saturation at high wind speed like for radars.
- ✓ Ifremer has developed a SMOS wind speed GMF focused on high wind speed.





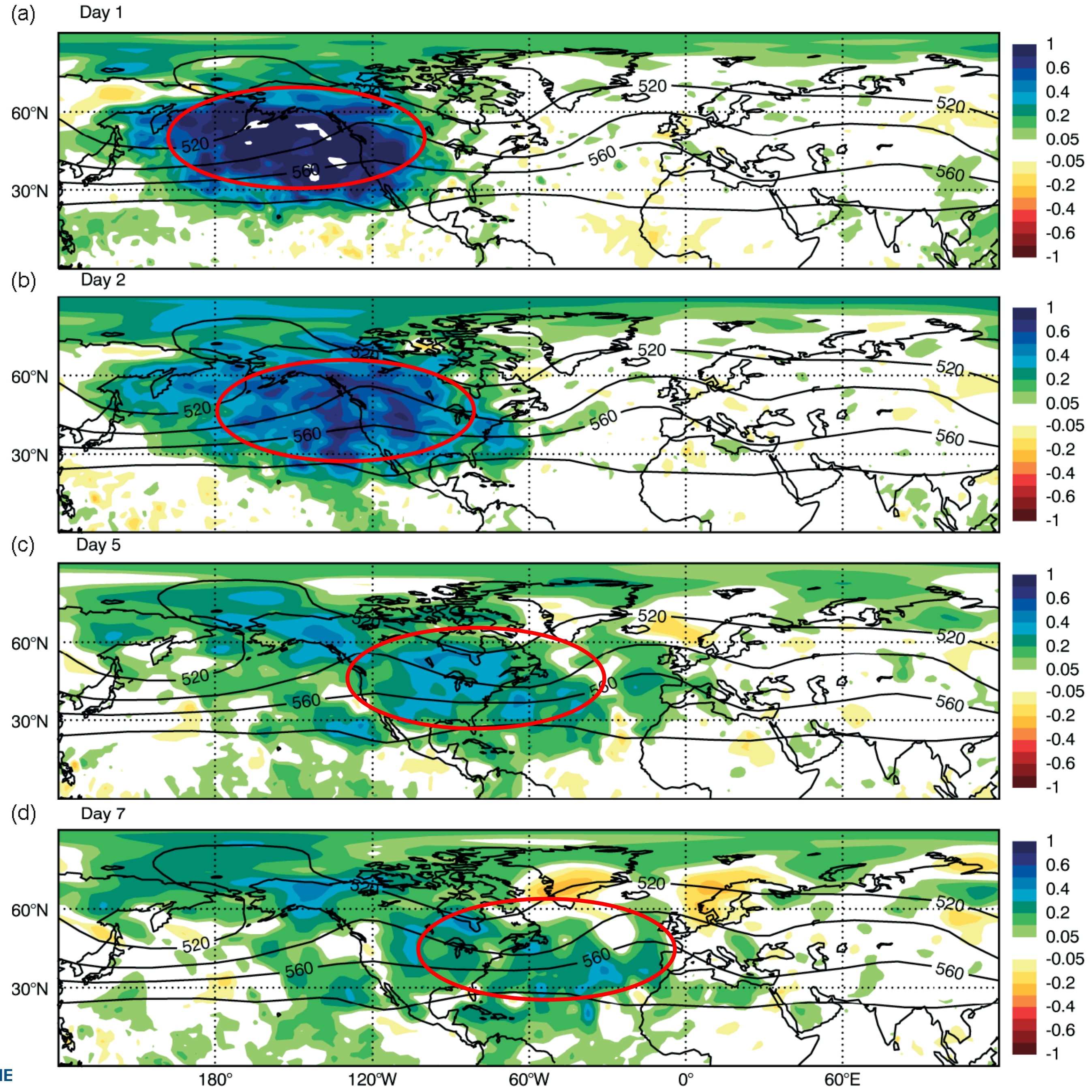
Assessment and potential for improvements.

1. Focusing on the Atlantic

- Due to circulation in the atmosphere, impact of atmospheric data (or lack of data) propagates from eastwards. (e.g. Kelly et al., 2007)

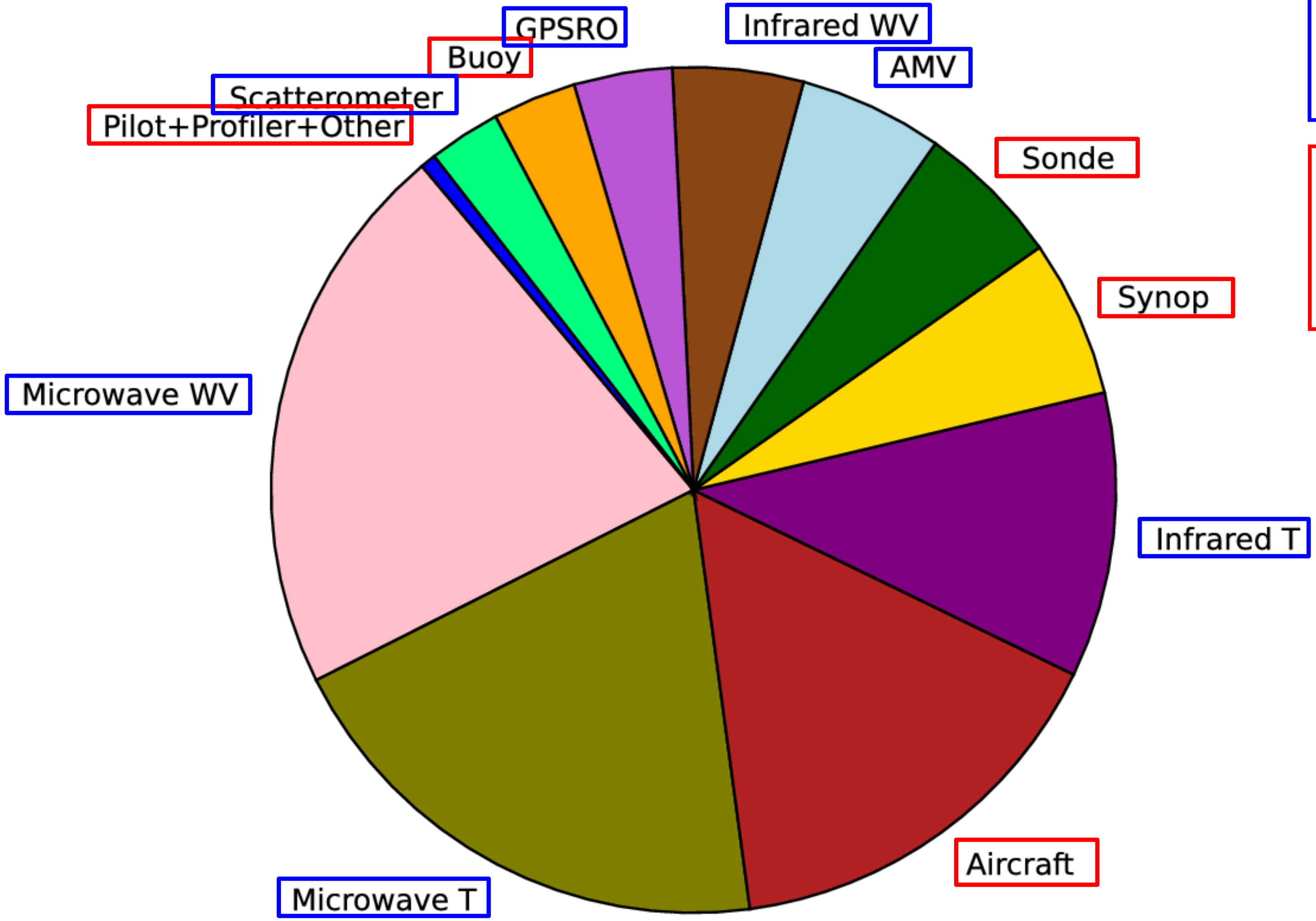
- Data on the North Atlantic impacts Europe in a couple of days.

- The Atlantic itself, feels the impact of data in the Pacific 5-7 days before.



- G. Kelly, J.-N. Thepaut, R.o Buizza and C. Cardinali (2007): “The value of observations. I: Data denial experiments for the Atlantic and the Pacific”, Q. J. R. Meteorol. Soc. 133: 1803–1815, DOI: 10.1002/qj.150

2. ECMWF 24 Forecast Impact (FSOI) – Example from February 2018:



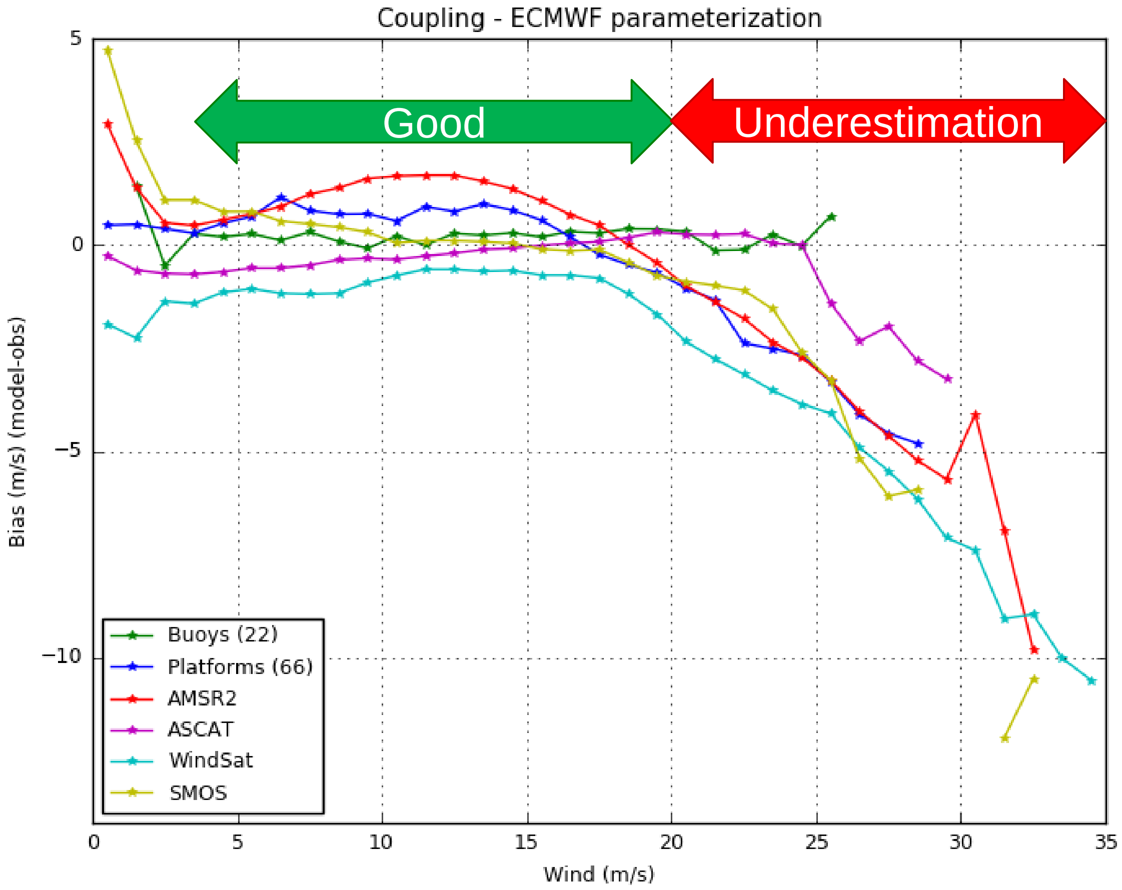
70% of 24h forecast impact comes from satellite data

30% of 24h forecast impact comes from in-situ data

Adapted from Alan Geer's ECMWF Annual Seminar 2018 talk

3. Need for reference observation dataset for high winds

- Model: good agreement for 3-20 m/s, underestimation for strong winds
- For strong winds:
  - ASCAT and buoys observations agree well with each other, giving the lowest wind.
  - AMSR2, SMOS and platforms are also coherent with each other, giving higher wind speed values.
  - ASCAT strong winds seem to be underestimated compared to other data.
  - Clear bias between buoys and platforms, strong winds from buoys could be underestimated?
  - Why such a good agreement between ASCAT/buoys and AMSR2/platforms?



Lucia Pineau-Guillou et al. (2017)

4. Future of Scatterometer data:

- Many scatterometer sensors flying at the moment:
  - C-band sensors on Metop-A, Metop-B, Metop-C (EUMETSAT)
  - Ku-band sensors on ScatSat-1 (ISRO), HY-2B (NSOAS), CFOSAT (CNES/CNSA)
  - At ECMWF we are using Metop-A/B. Metop-C and ScatSAT assessments are ongoing.

- Planned launches in the near future: Oceansat-3 (ISRO), FY-3E (CMA)

- Long-term planned missions: EPS-SG (EUMETSAT) with 3 SCA instruments in the 2022-2043 timeframe

- The availability of other atmosphere/ocean interface measurements like surface ocean currents and surface stress is desirable to improve the way scatterometer winds are retrieved and used in NWP.

5. Future of Altimeter and SAR data:

- Many altimeters are flying at the moment:
  - Sentinel-3A and 3B.
  - Jason-3 and Jason-2.
  - CryoSat-2.
  - SARAL/AltiKa.
  - Others: HY-2B, CFOSAT
- Planned launches in the near future: Sentinel-6A and 6B, Sentinel-3C and 3D.
- The availability of wide swath altimeters is useful.

- SAR:
  - Sentinel-1A and 1B.
  - Planned: Sentinel-1C and 1D.

6. Need for other wind measurements

- **L-band microwave wind measurements:**
  - SMOS winds have great potential in providing ocean winds in extreme conditions (TC, extra-tropical storms).
  - The continuous availability of L-band microwave wind measurements in the future is of great value/interest.

- **Wind profiles:**
  - Aeolus is the first satellite mission to acquire profiles of Earth’s wind on a global scale.
  - Continuous availability of such data is important to improve weather forecasts.

7. List of desirable extra measurements:

- Provision of the following from space with good accuracy over the whole globe in near real time is highly desirable *(some have already been mentioned in the previous slides)*:
  - surface ocean currents (accompanied with wind vectors if possible)
  - surface stresses
  - wind profiles
  - L-band microwave surface wind measurements
  - swath measurements of sea state (significant wave height)
  - atmospheric surface pressure

Thanks

Extra

Earth surface modelling components @ECMWF in 2018

- **NEMO3.4**

  NEMO3.4 (Nucleus for European Modelling of the Ocean)

  Madec et al. (2008)

  Mogensen et al. (2012)

  ORCA1_Z42: 1.0° x 1.0°

  ORCA025_Z75 : 0.25° x 0.25°

- **EC-WAM**

  ECMWF Wave Model

  Janssen, (2004)

  Janssen et al. (2013)

  ENS-WAM : 0.25° x 0.25°

  HRES-WAM: 0.125° x 0.125°

- **LIM2**

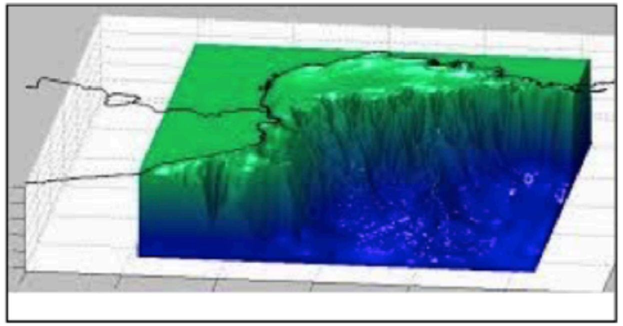
  The Louvain-la-Neuve Sea Ice Model

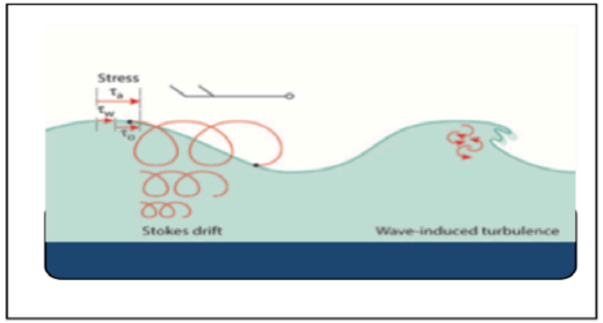
  Fichefet and Morales Maqueda (1997)

  Bouillon et al. (2009)

  Vancoppenolle et al. (2009)

  ORCA025_Z75 : 0.25° x 0.25°





- **Hydrology-TESSEL**

  Balsamo et al. (2009)
  van den Hurk and Viterbo (2003)

  Global Soil Texture (FAO)

  New hydraulic properties

  Variable Infiltration capacity & surface runoff revision

- **NEW SNOW**

  Dutra et al. (2010)

  Revised snow density

  Liquid water reservoir

  Revision of Albedo and sub-grid snow cover

- **NEW LAI**

  Boussetta et al. (2013)

  New satellite-based

  Leaf-Area-Index

- **SOIL Evaporation**

  Balsamo et al. (2011),

  Albergel et al. (2012)

- **H_2O / E / CO_2**

  Integration of

  Carbon/Energy/Water

  Boussetta et al. 2013

  Agusti-Panareda et al. 2015

- **Lake & Coastal area**

  Mironov et al (2010),

  Dutra et al. (2010),

  Balsamo et al. (2012, 2010)

  Extra tile (9) to for sub-grid lakes and ice

  LW tiling (Dutra)

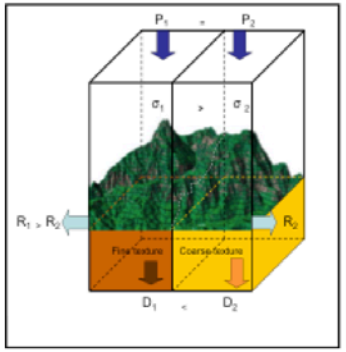
- **Enhance ML**

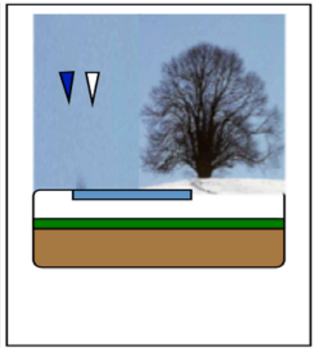
  Snow ML5

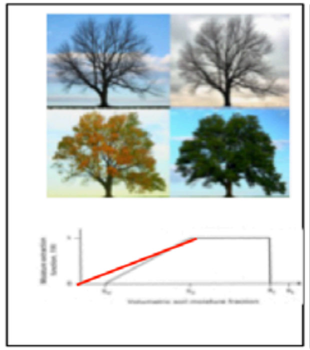
  Soil ML9

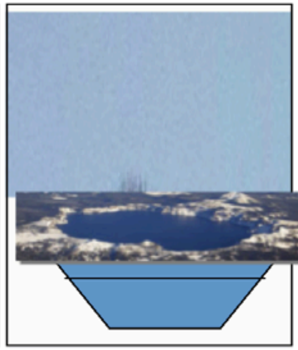
  Dutra et al. (2012, 2016)

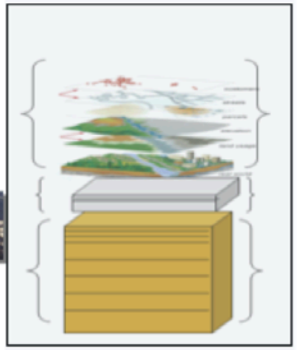
  Balsamo et al. (2016)











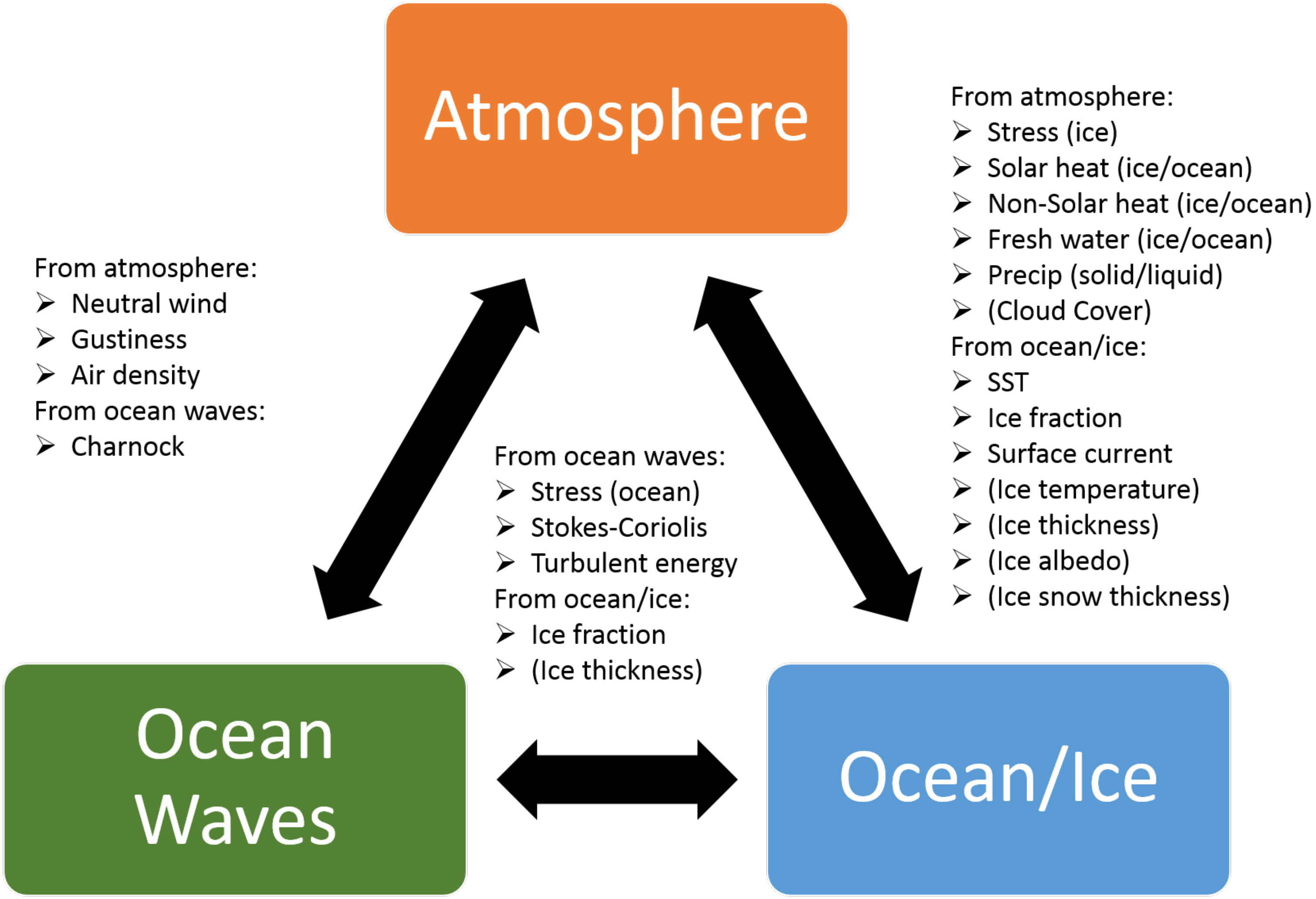
Atmos Land Resol.	**ECMWF in 2018**
80 km	ERAI
32 km	ERA5^{+} SEAS5^{+*}
18 km	ENS^{+*}
9 km	HRES^{+*}

*Ocean
used across forecast systems and in Ocean reanalysis

(*migration completed with HRES-coupled operational from the 5th June 2018)

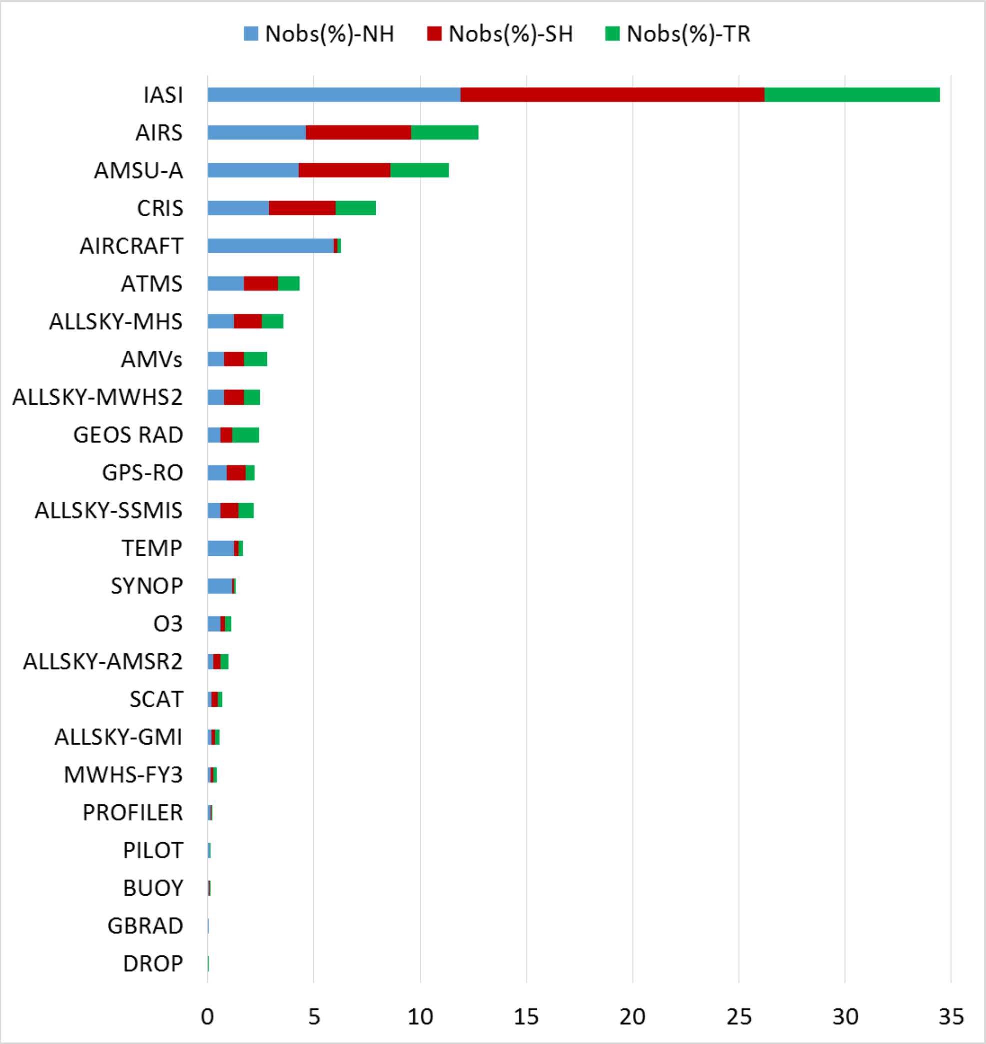
+Land
used across forecast systems and new Climate reanalysis

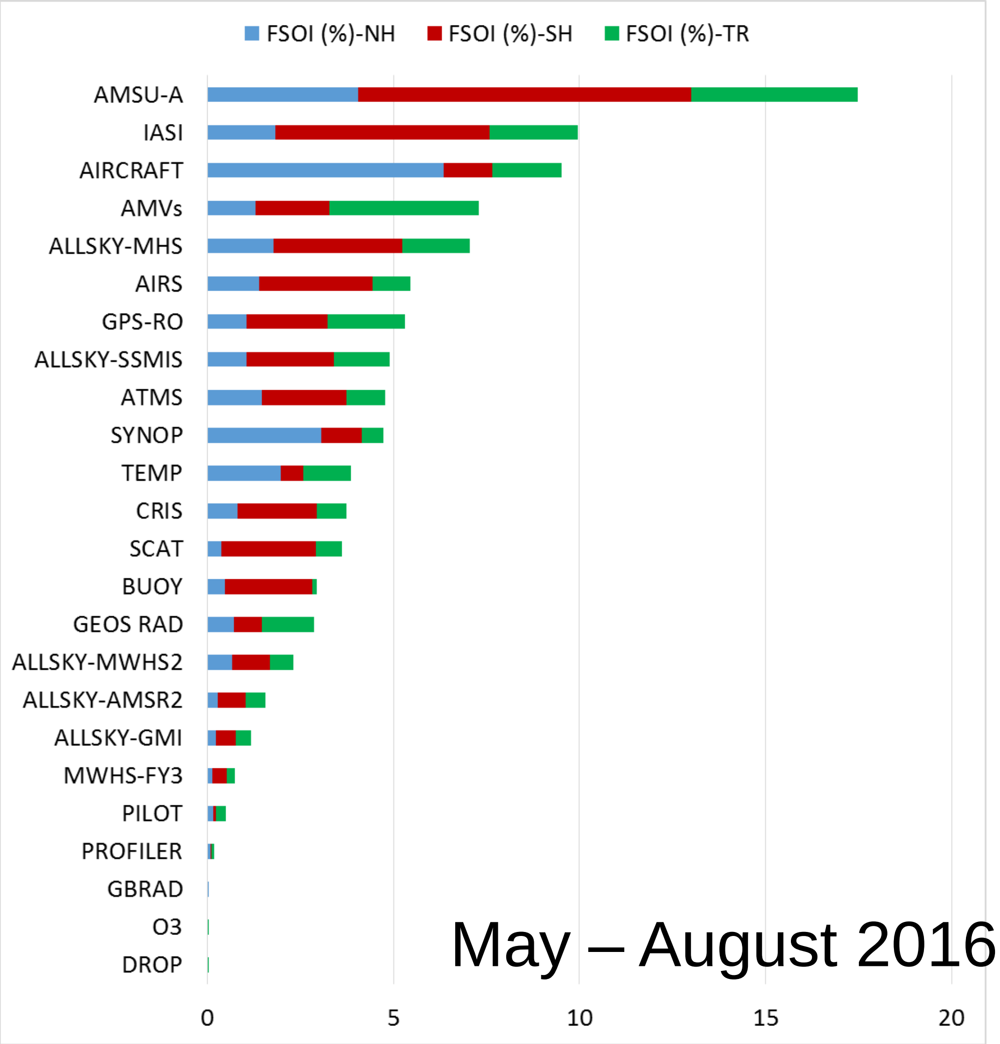
Data exchanges in the ECMWF coupled model



Fields in () are not currently used in operations

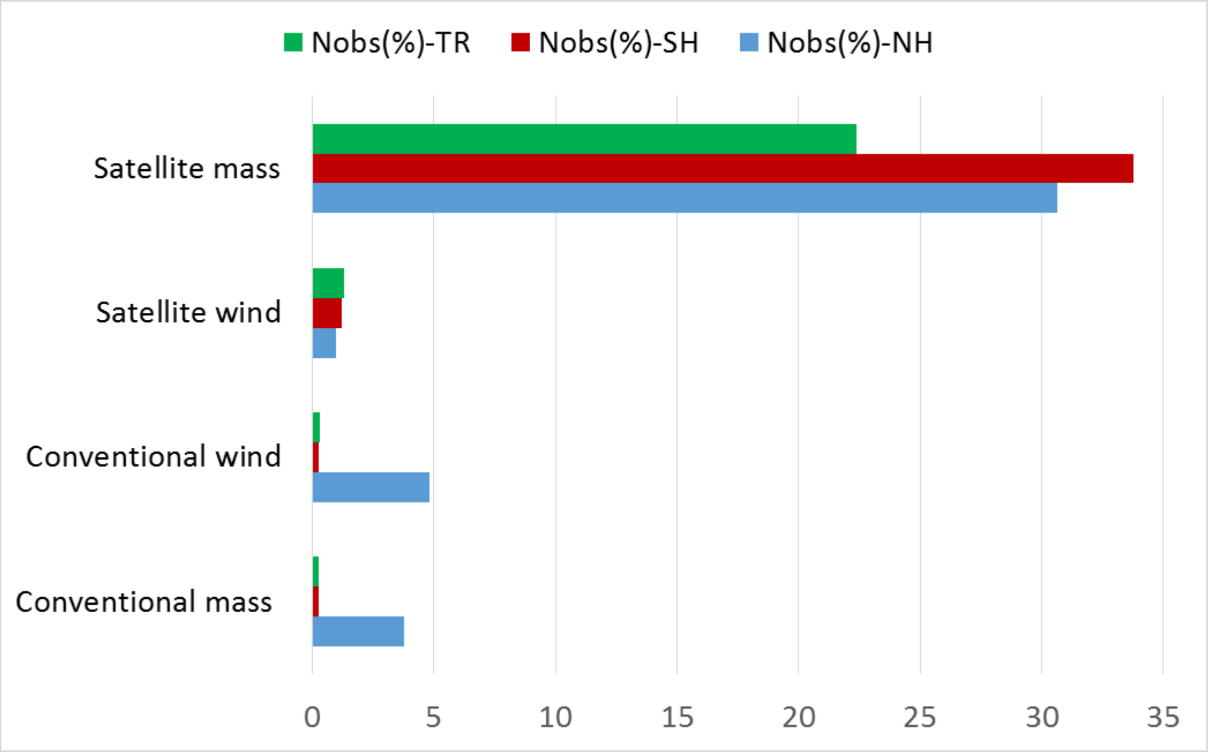
Nobs and total FSOI by instrument: NH, SH, TR

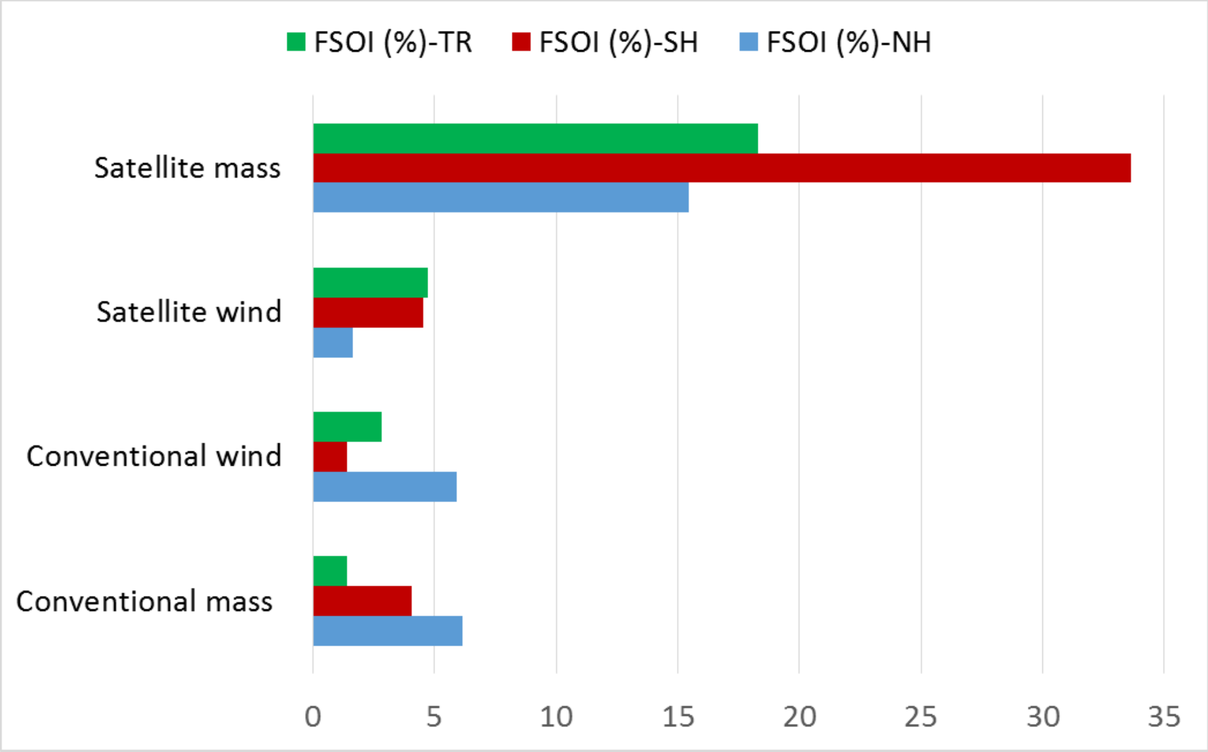




FSOI: Forecast Sensitivity to Observation Influence (24h forecast), by Cristina Lupu.

Nobs and total FSOI: Mass and wind





May – August 2016

FSOI: Forecast Sensitivity to Observation Influence (24h forecast), by Cristina Lupu.

Winter Pacific forecasts: Verification of mean 500 hPa geopotential *rmse* up to day 10 for SEAOUT in grey dotted and SEAIN in black: Both experiments are verified using ECMWF operational analysis verified in the North Atlantic