Assimilation of Scatterometer Data in a Coupled System

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with contributions from Tony McNally, Saleh, Abdalla, Sean Healy, Patrick Laloyaux, Phil Brown, Eric de Boisseson, Dinand Schepers

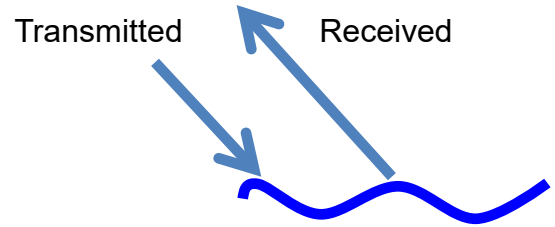
Joint EUMETSAT NWP_SAF / ECMWF Workshop on Satellite Observations of the Earth System Interfaces

ECMWF

Scatterometer: an air-ocean interface sensor

A Scatterometer is an active microwave instrument (side-looking radar)

- Day and night acquisition
- Not affected by clouds



From scatterometers, we retrieve the ocean surface winds (10m ocean wind vector)

$$\sigma \sim \frac{\text{received power}}{\text{transmitted power}}$$

backscatter (σ_0 sigma-nought)

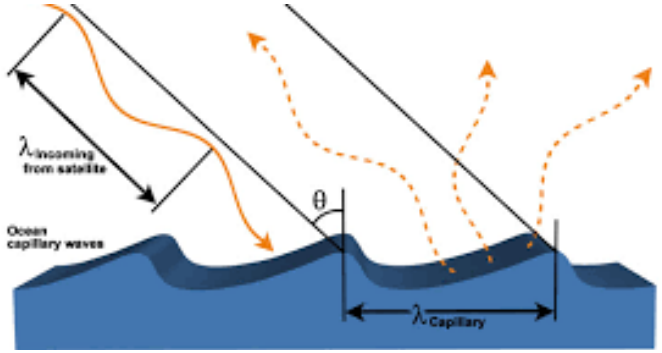
Ocean surface winds:

- affect the full range of ocean movement
- modulate air-sea exchanges of heat, momentum, gases, and particulates

(andrej67/iStock/Getty Images)

Scatterometer

Bragg scattering occurs from the ocean capillary-gravity waves (cm-range) that are in resonance with the microwaves



Measurements sensitive to the **ocean-surface roughness** due to capillary gravity waves generated (not only!!!) by local wind conditions (**surface stress**)

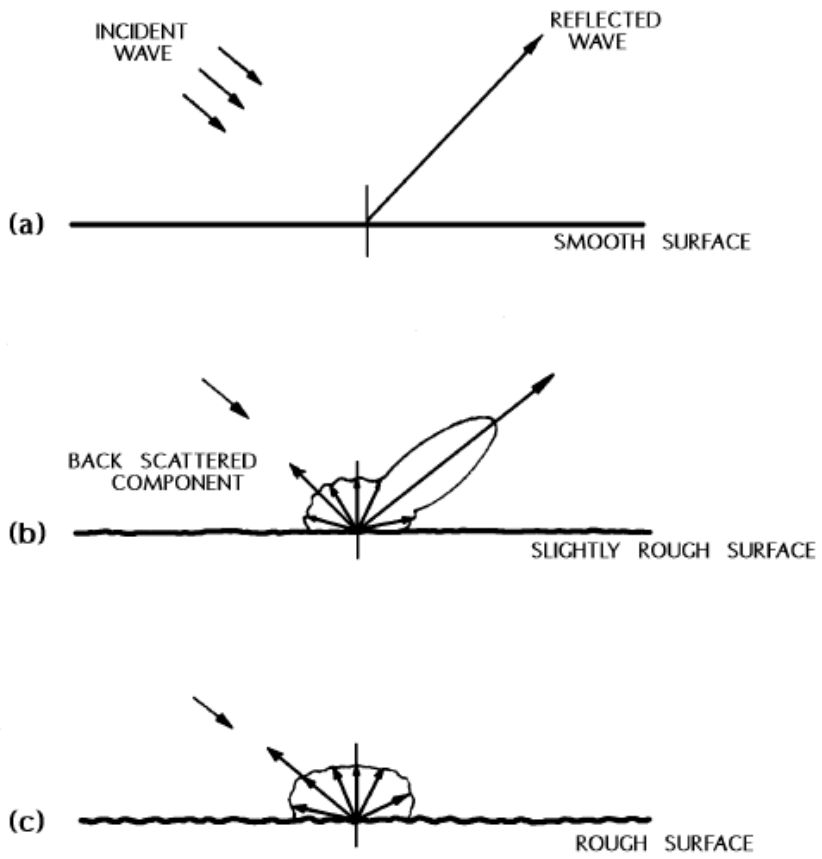
How do we extract a geophysical parameters from backscatter?

- Ideally, we should collocate backscatter to with *surface stress* observations
- In practice, collocate to buoy and 10m model winds (empirical relationship)

Backscatter *highly* depends on:

- Wind speed
- Relative direction between the surface wind and look angle

Dependency of the backscatter on... Wind speed

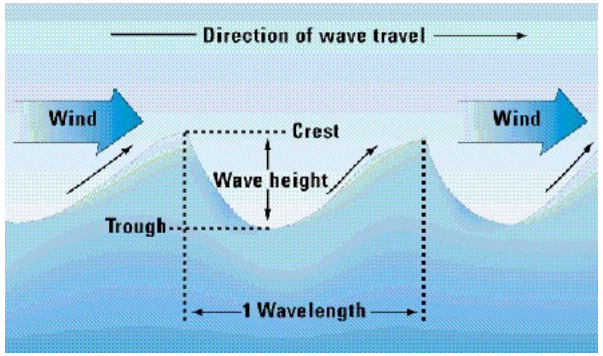


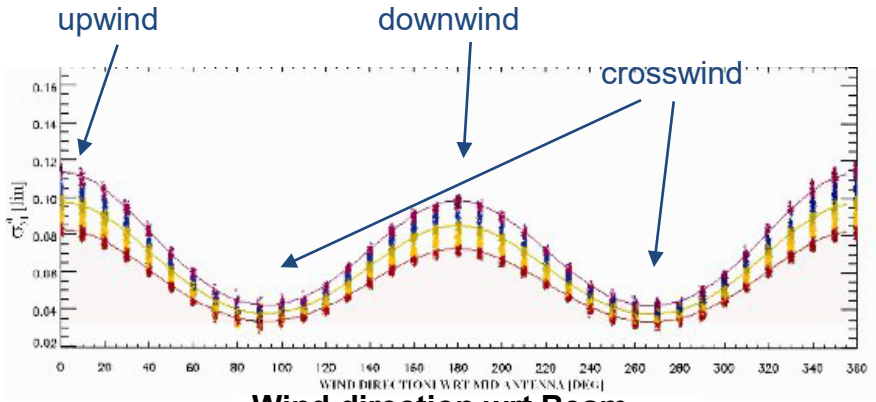
Stronger winds → higher ocean surface roughness → smaller return signal (backscatter!)

Dependency of the backscatter on... Wind direction

upwind

downwind



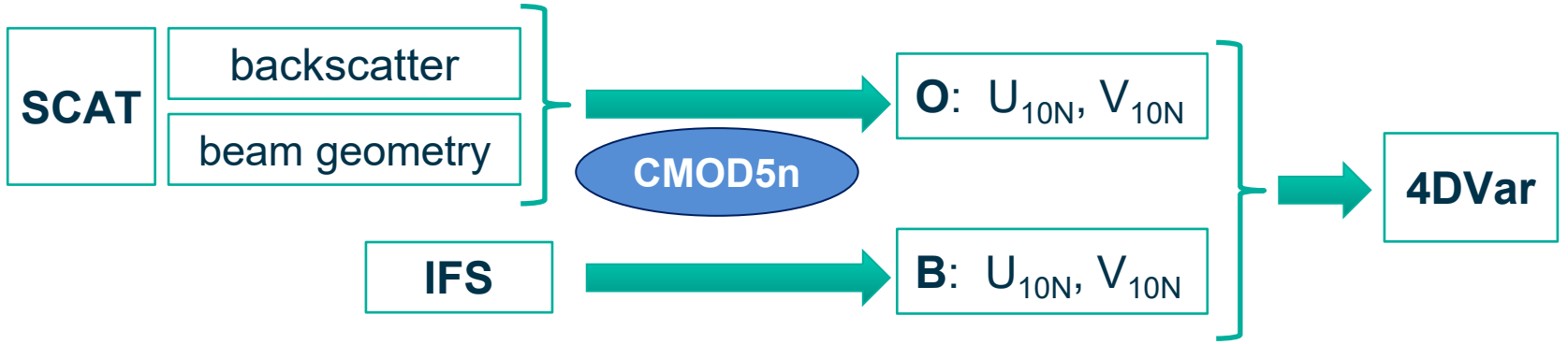


Wind direction wrt Beam

- Asymmetry Upwind – Downwind (particularly small)
- Asymmetry Upwind – Crosswind

Using multiple observations from different azimuth angles improves the accuracy of the derived wind direction

Current operational assimilation approach at ECMWF



C-band (ASCAT-B/C):

- In-house wind inversion (from 25km grid L1 to L2) using CMOD5n (not the state of the art GMF!)
- 2 wind solutions are provided: the best one is selected by comparing to the background wind fields
- ASCAT observations thinned to 50 km
- Max wind speed assimilated: 35 m/s

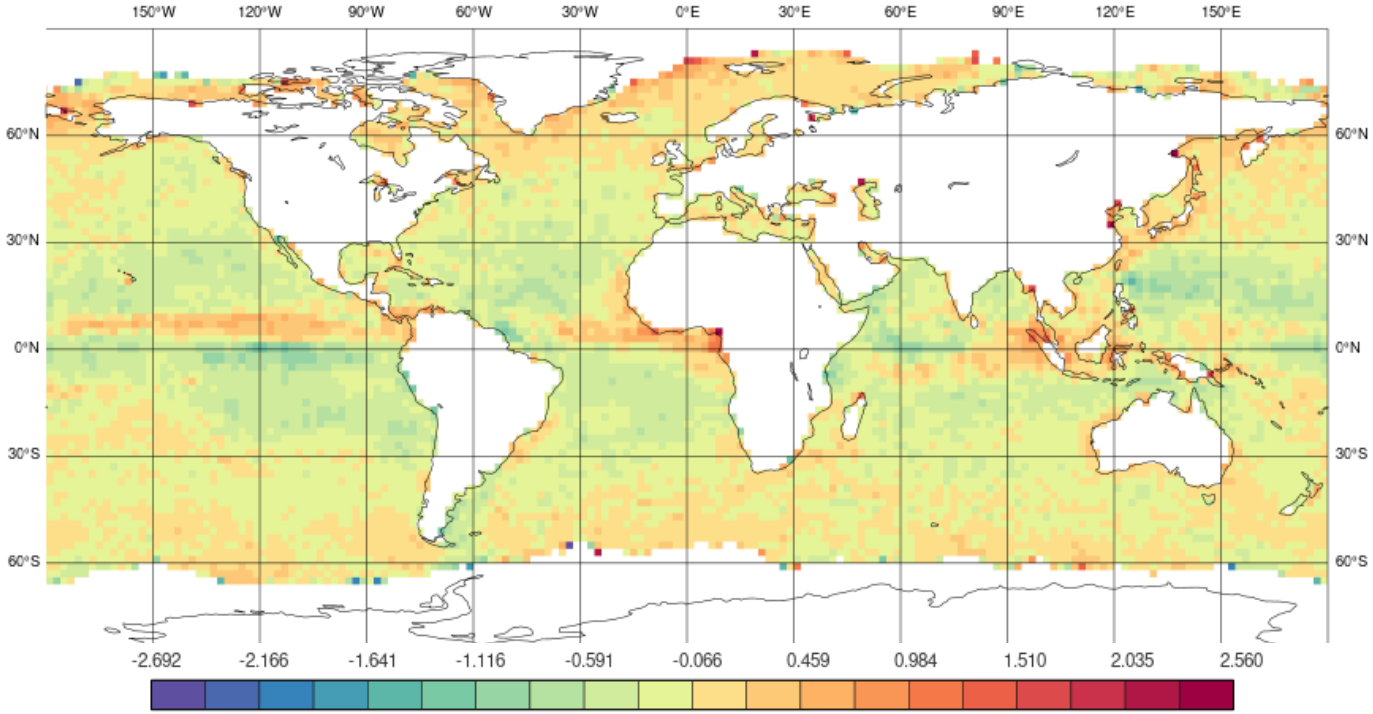
Ku-band (HY-2B/C/D):

- OSI SAF L2 products (50km grid)
- Max wind speed assimilated: 25 m/s

Wind vectors assimilated as **10m equivalent neutral winds**

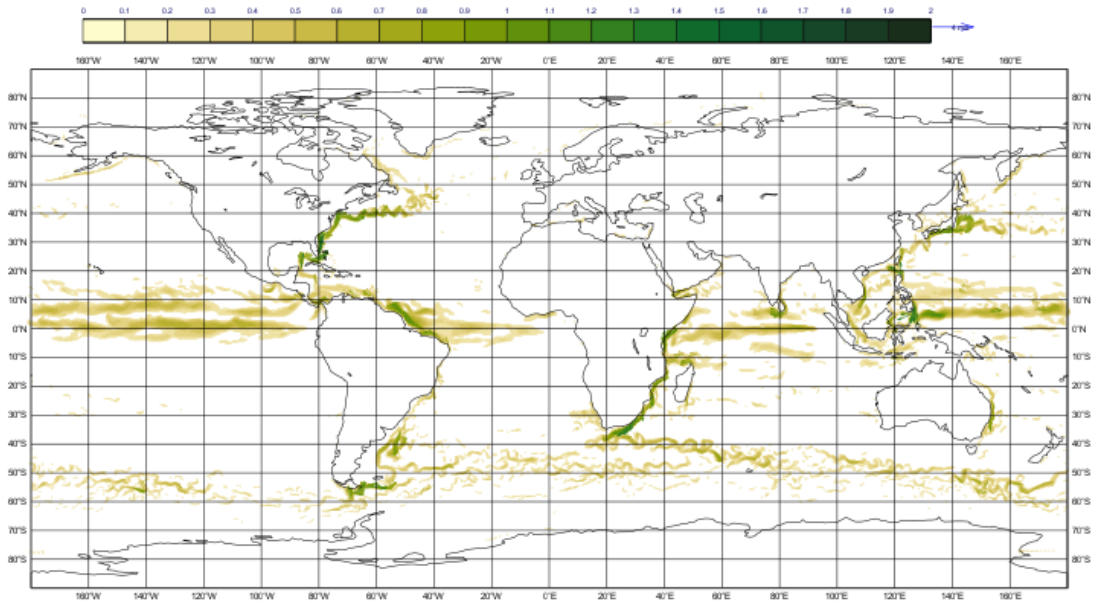
Background Departure

ASCAT-C Wind speed O-B [30 Sept 24 – 19 Nov 2024]

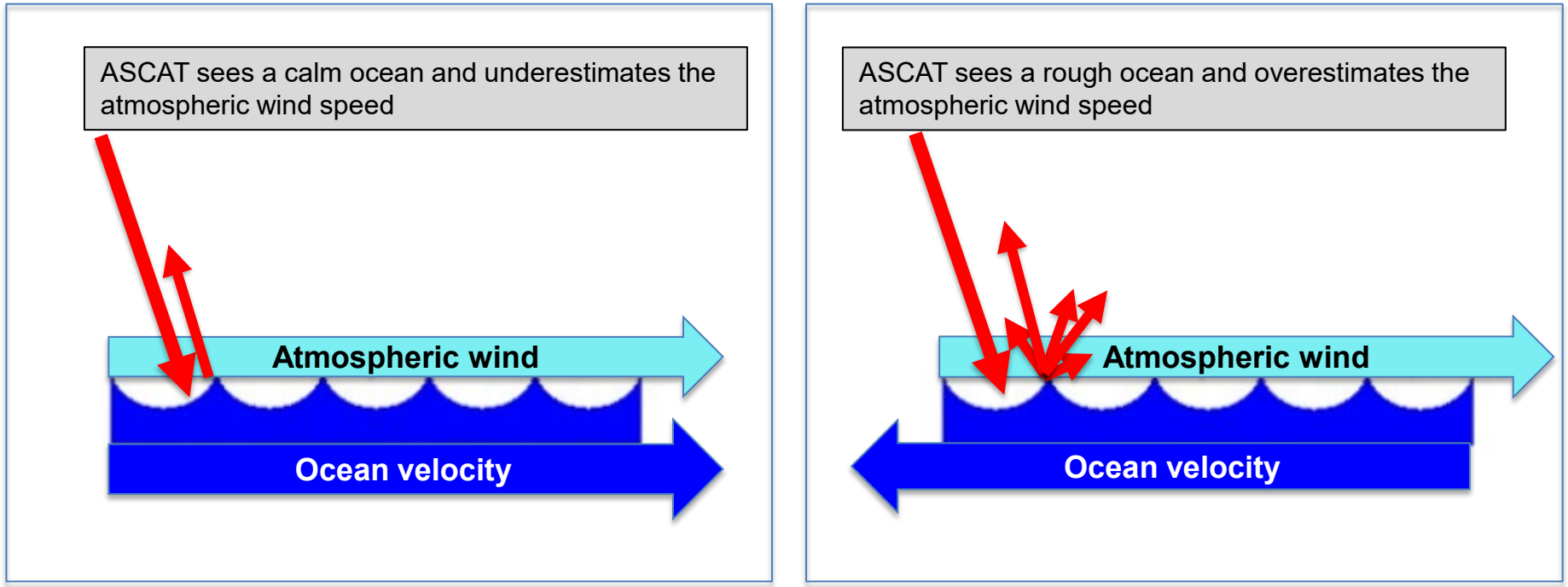


Wind speed bias in the Tropics:
also due to Ocean Current?

Ocean currents from OCEAN5



Scatterometer and Ocean Currents



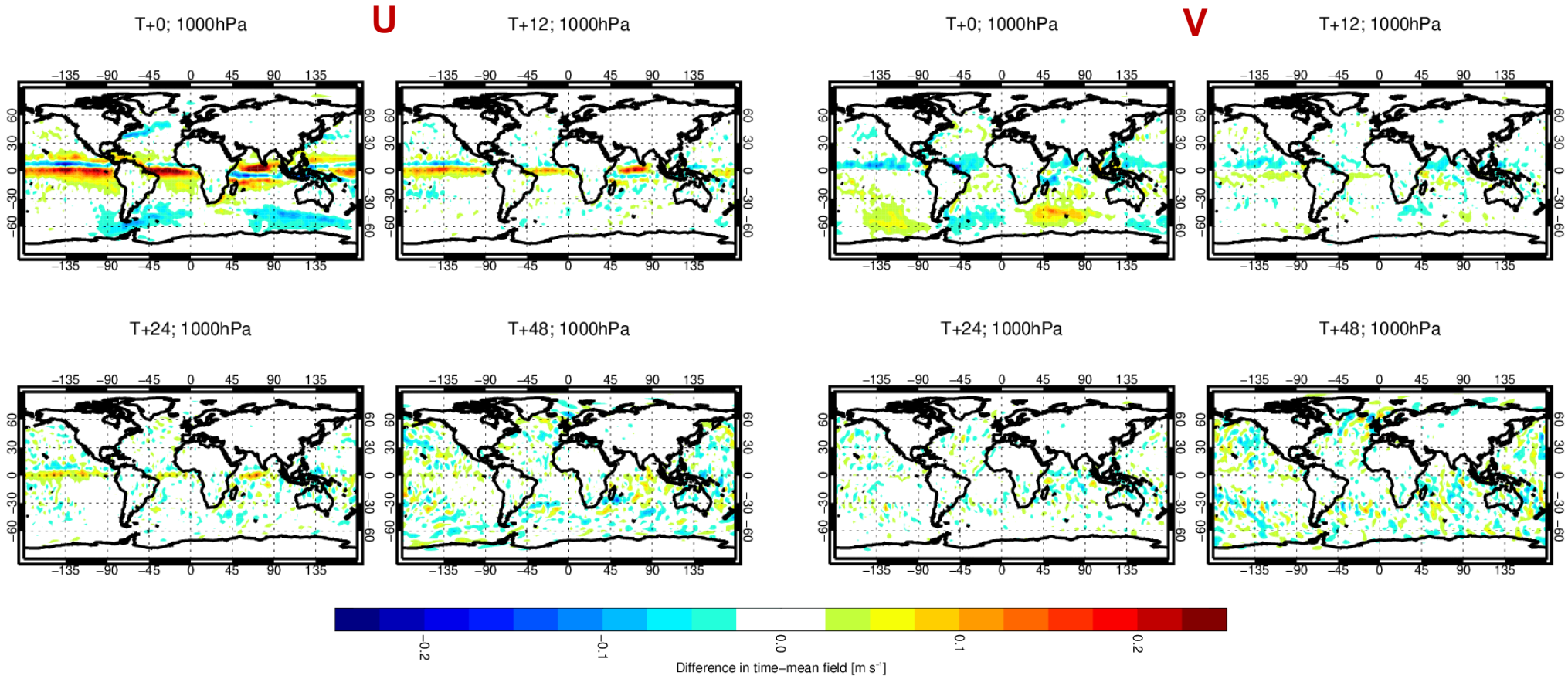
- The scatterometer ”sees” the ocean currents
- In operations, the scatterometer observations operator *does not account* for them but…
- This will happen in CY49r2 used for ERA6

Impact of ocean currents in the scatterometer assimilation

OSEs to separate the impact of the ocean coupling for SCAT only (Dec 21 – Feb 22):

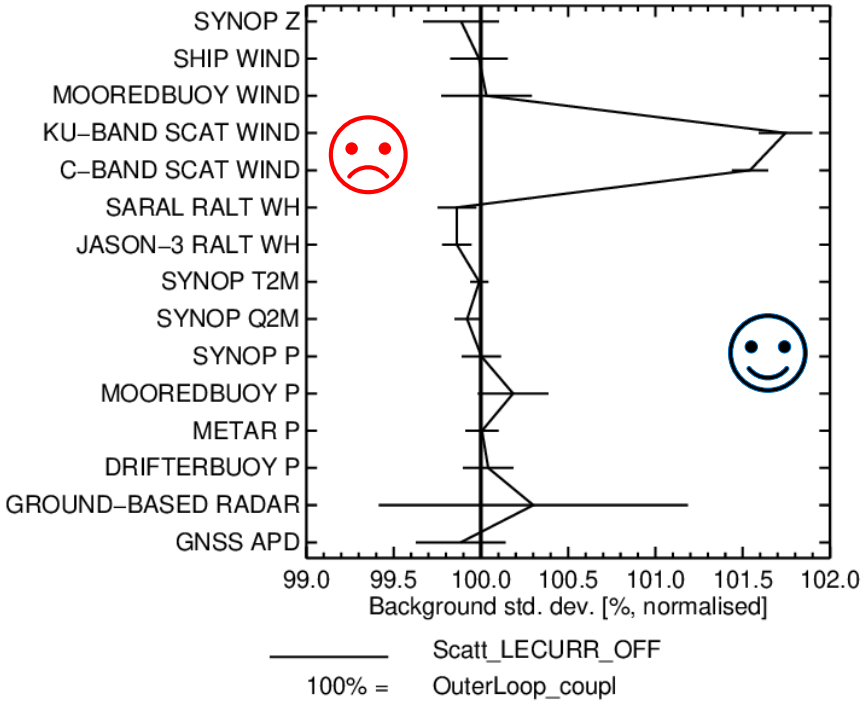
- **OuterLoop_coupling:** ERA6-like configuration where ocean currents are used in the scatt obs oper, BL, wave model, etc
- **Scatt_LECURR_OFF:** ocean currents off for the scatterometer observation operator only

Changes in mean component: Scatt_LECURR_OFF – OuterLoop_coupling

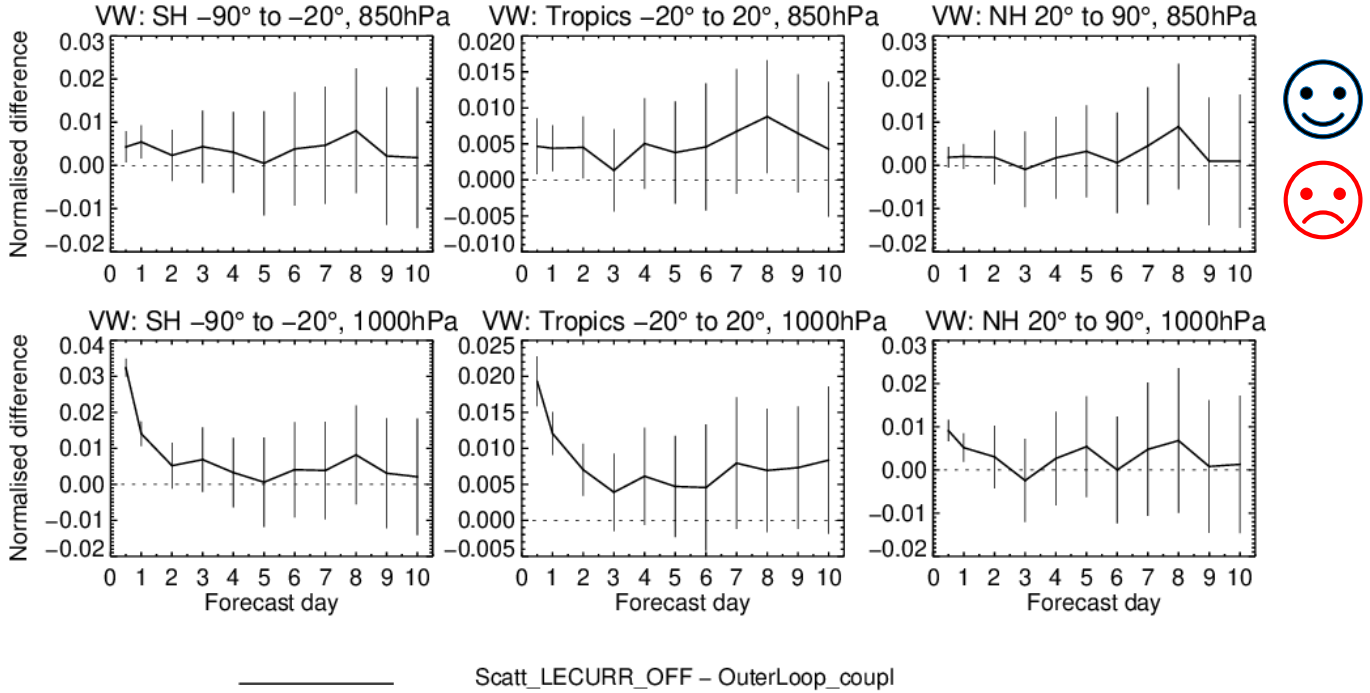


Impact of ocean currents in the scatterometer assimilation

Changes in short-range fc departure stats
Surface observations
Normalized SD (%) to OuterLoop_coupl

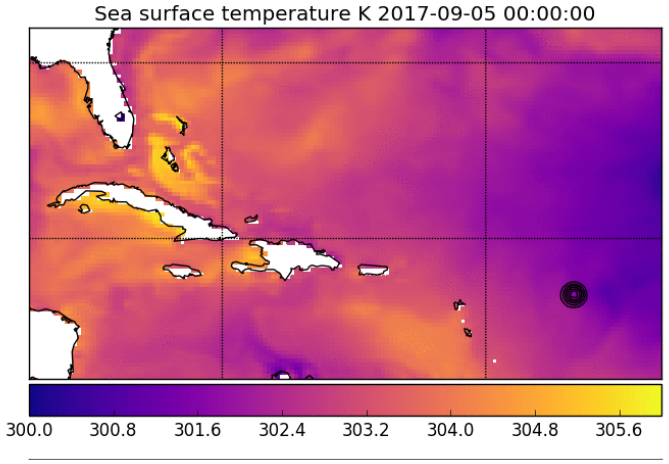


Changes in vector winds RMS forecast error
Scatt_LECURR_OFF - OuterLoop_coupl



What about the impact of Scatterometer on the ocean surface?

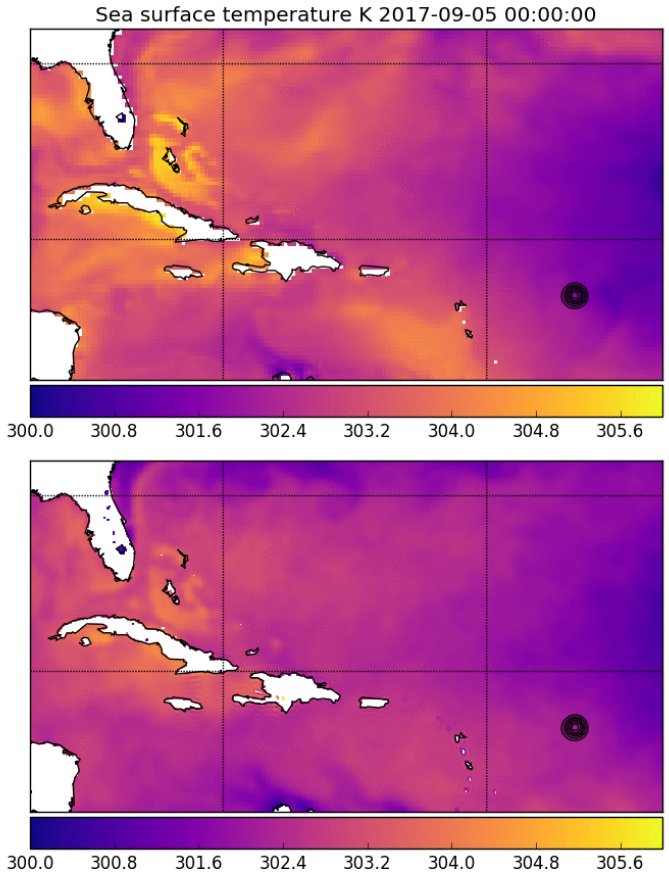
Coupled Data Assimilation (CDA)



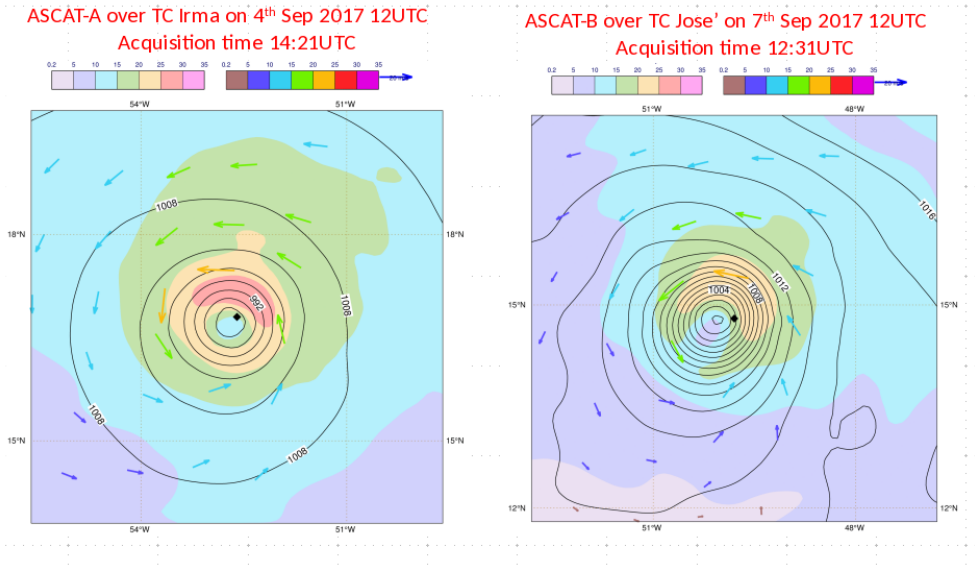
In the **coupled assimilation** the SST shows a clear and immediate impact on SST of the storm winds mixing the ocean (cold wake) and the storm's arrival in the Caribbean damping the usual pronounced diurnal cycle in the SST

Irma/Jose with ocean – atmosphere DA coupling

Scatterometer impact on the ocean surface



What is the role of ASCAT (and JASON) in the coupled data assimilation during Irma and Jose?



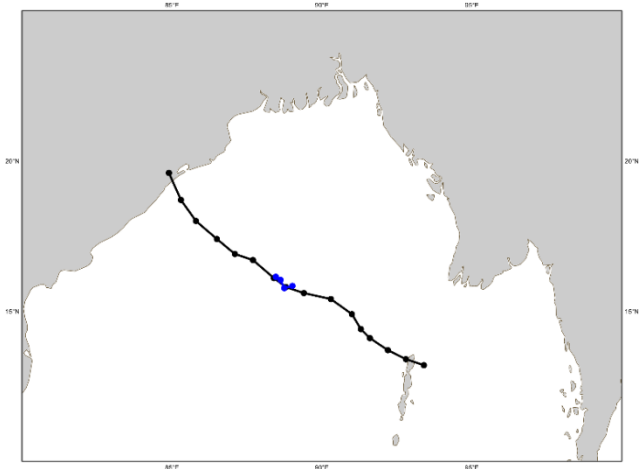
In CDA ASCAT gives SST information below Tropical Cyclones

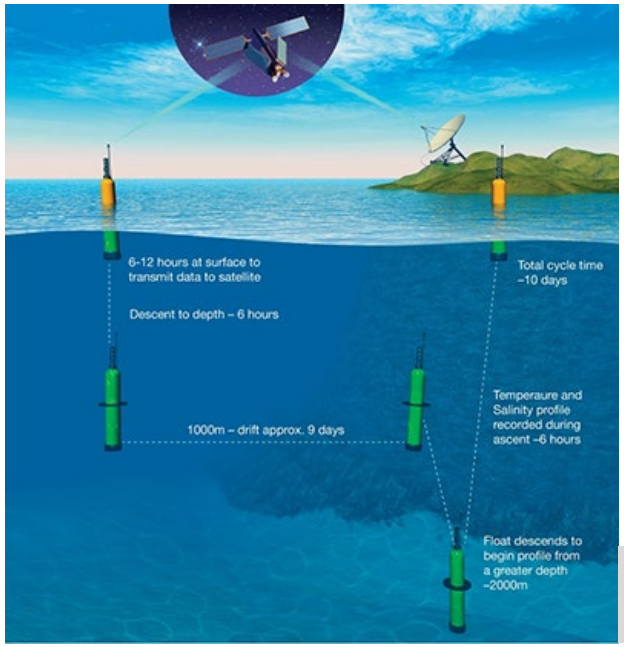
ASCAT sees through the cloud and rain (IR/MW cannot) and informs the coupled analysis of the surface roughening below the storm, in turn influencing the ocean mixing and thus the SST !

Quantifying heat exchange between the storm and ocean surface is an important factor in predicting the intensification / de-intensification of Tropical Cyclones.

Impact of scatterometer winds …on the ocean parameters

Coupled Data Assimilation (CDA)

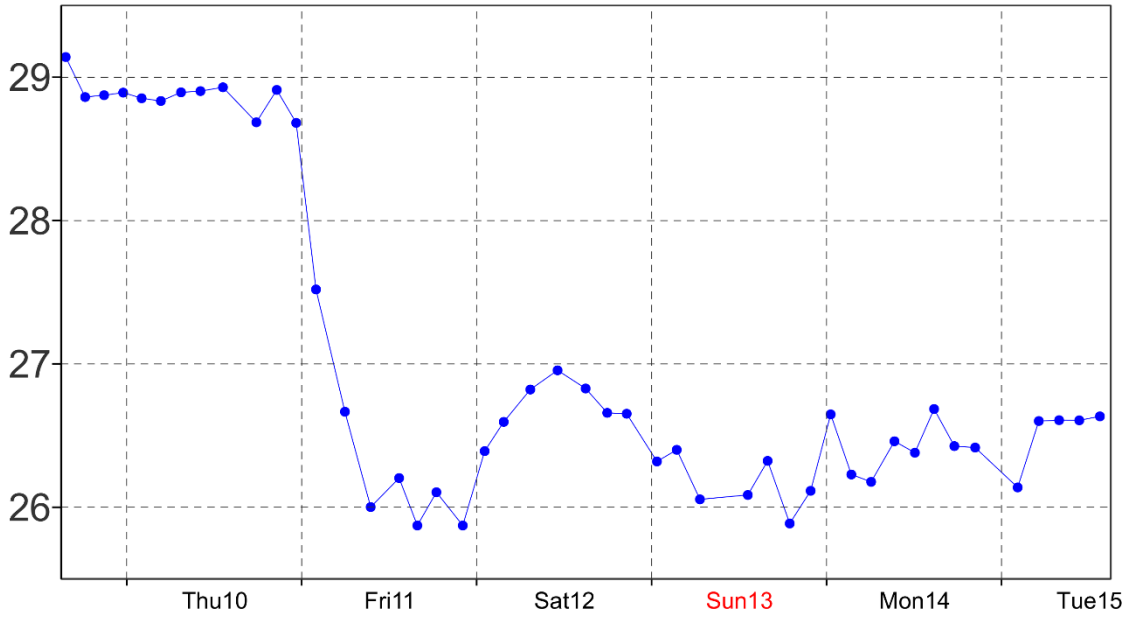




Focus on a specific weather event:

- TC Phailin
- Bay of Bengal
- formed on the 4th October 2013
- Argo probe with high-frequency measurements

Temperature measurements at 40-meter depth

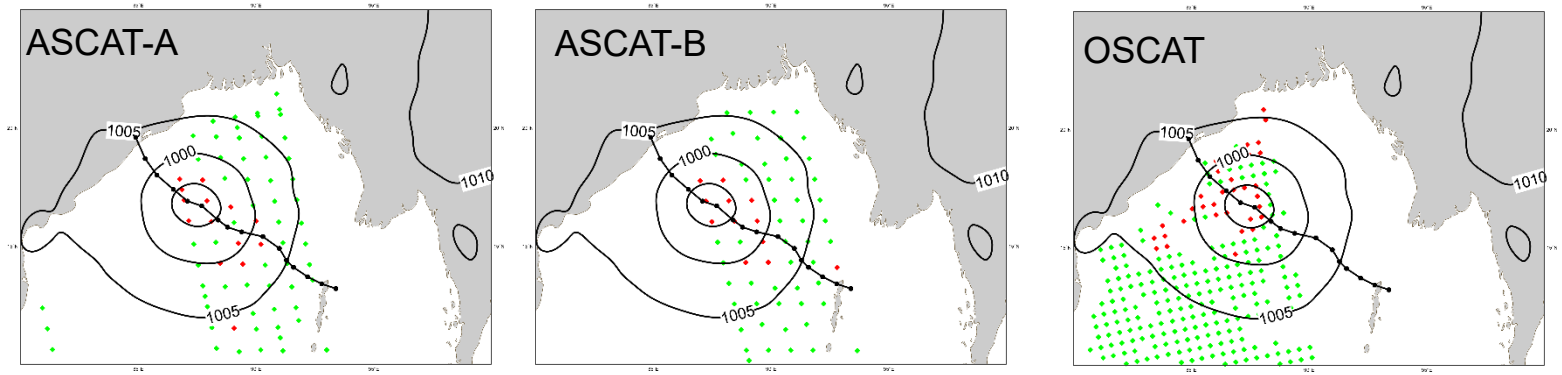


Impact of scatterometer surface wind data in the ECMWF coupled assimilation system
P. Laloyaux, J-N Thépaut and D. Dee. MWR, 2016

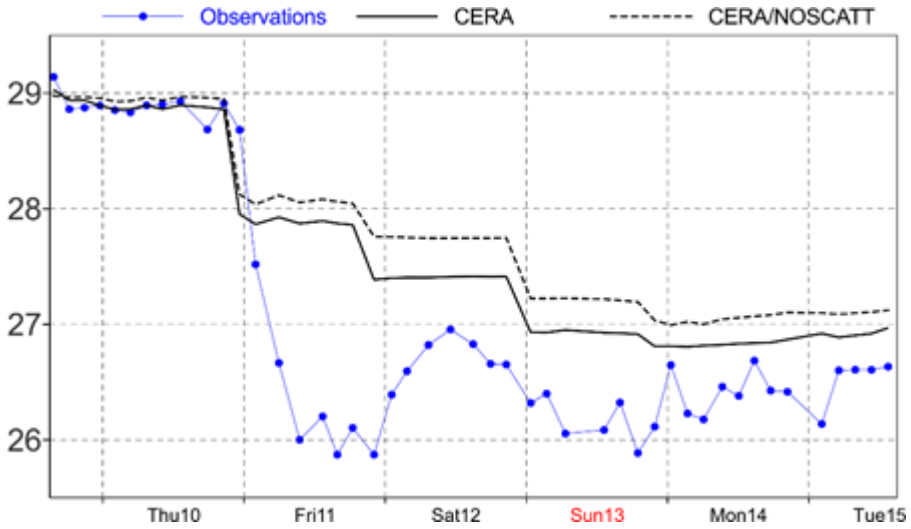
Impact of scatterometer winds …on the ocean parameters

TC Phailin

Wind measurements from scatterometers (ascending pass, 11 October 2013)

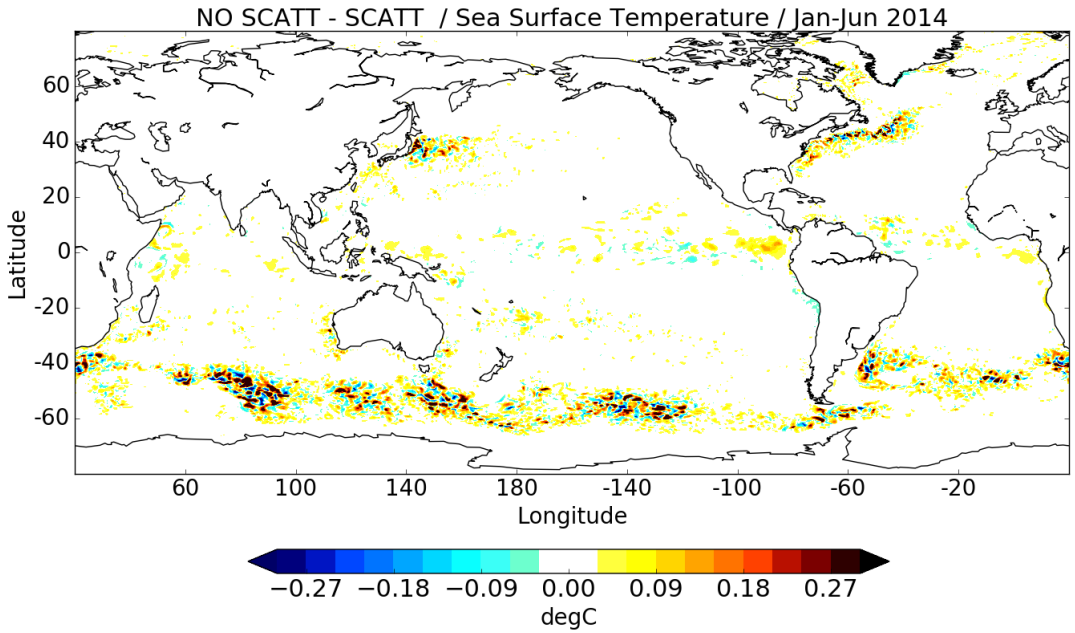


Ocean temperature analysis at 40-meter depth (scatterometer data are assimilated)

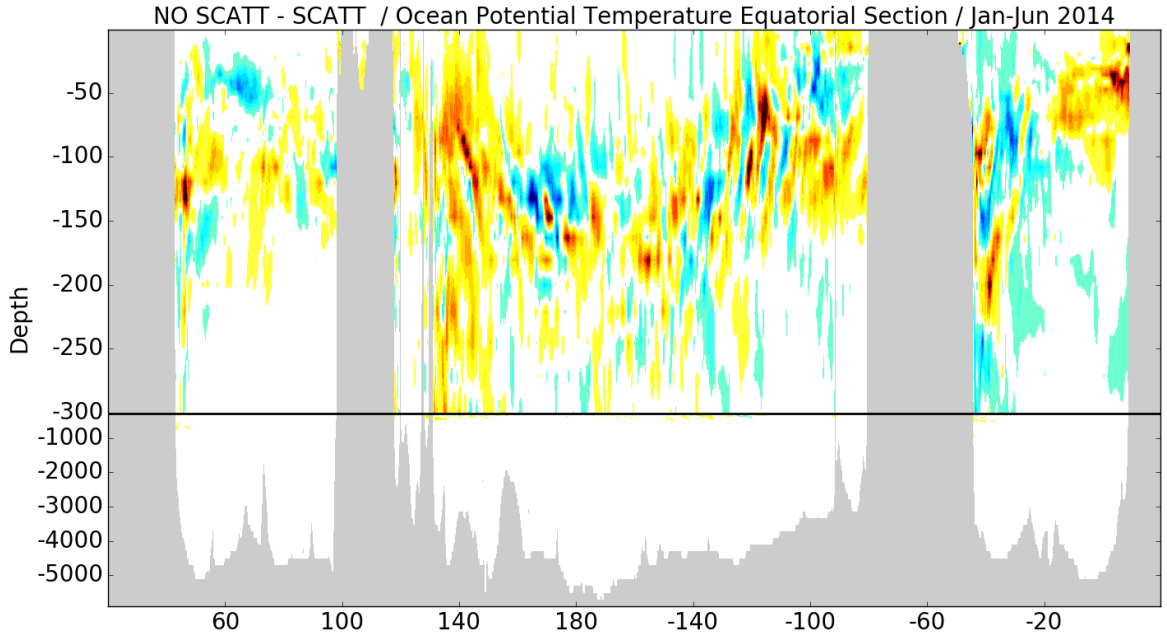


Coupled analysis with Scatterometer winds is closer to the observations with a stronger cold wake

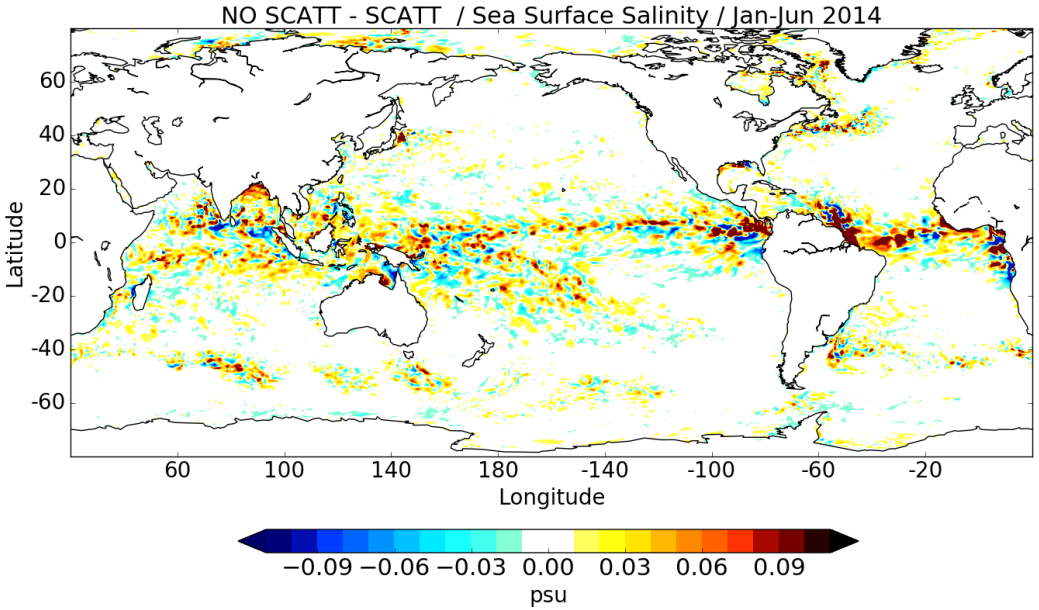
Impact of Scatterometer on Ocean Temperature



No SCATT – SCATT



Impact of Scatterometer on Ocean Salinity



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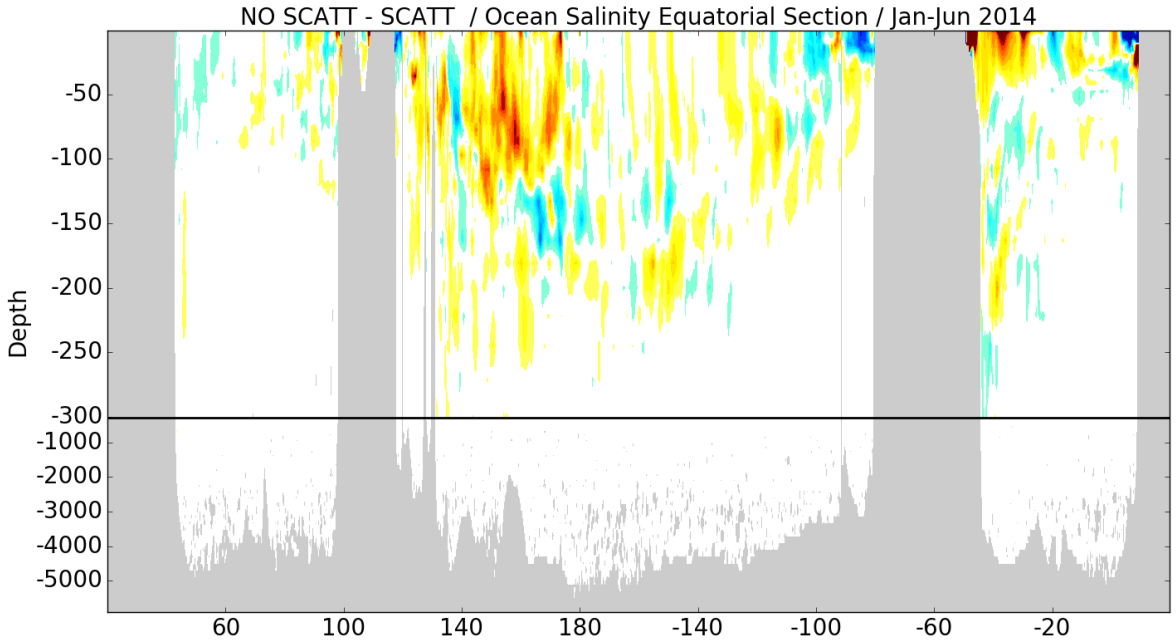


Assessment of Direct Assimilation of Sigma0 (using ML)

WHY?

- In IFS most of satellite observations are assimilated as L1 observations (e.g. radiances)

- Why scatterometer observations should be an exception?
  - 4D-Var systems is designed to handle ill-posed (== ambiguous) retrieval problems
  - We are routinely tackling increasingly non-linear forward problems in 4D-Var: ”All-sky, all surface, …”

- Some tests were performed in the past but cannot find examples/studies in the literature comparing the impact of assimilating ASCAT sigma0 vs wind retrievals in 3D/4D-Var system

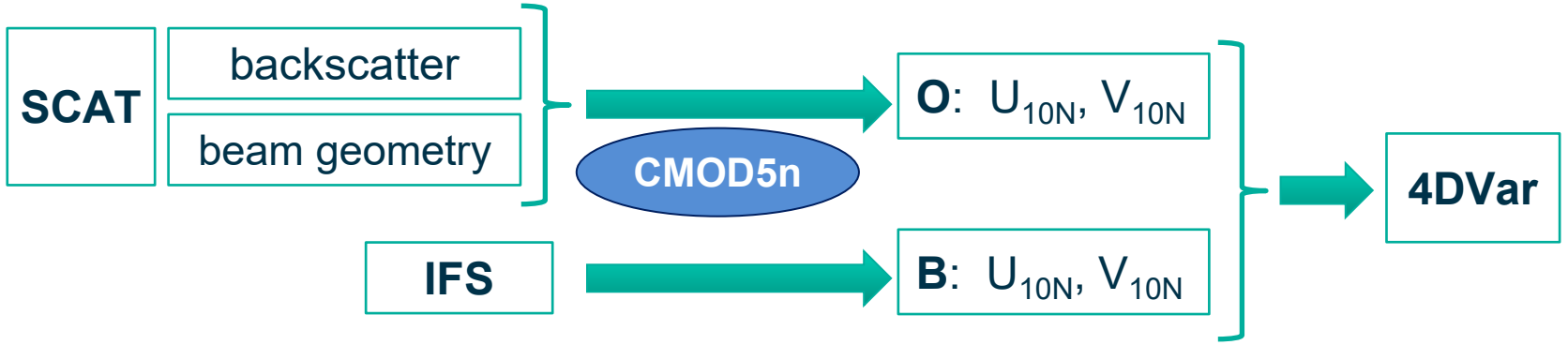
- Can we get closer to what a scatterometer actually measures assimilating backscatter?

- ***Revisiting the direct assimilation of sigma0***

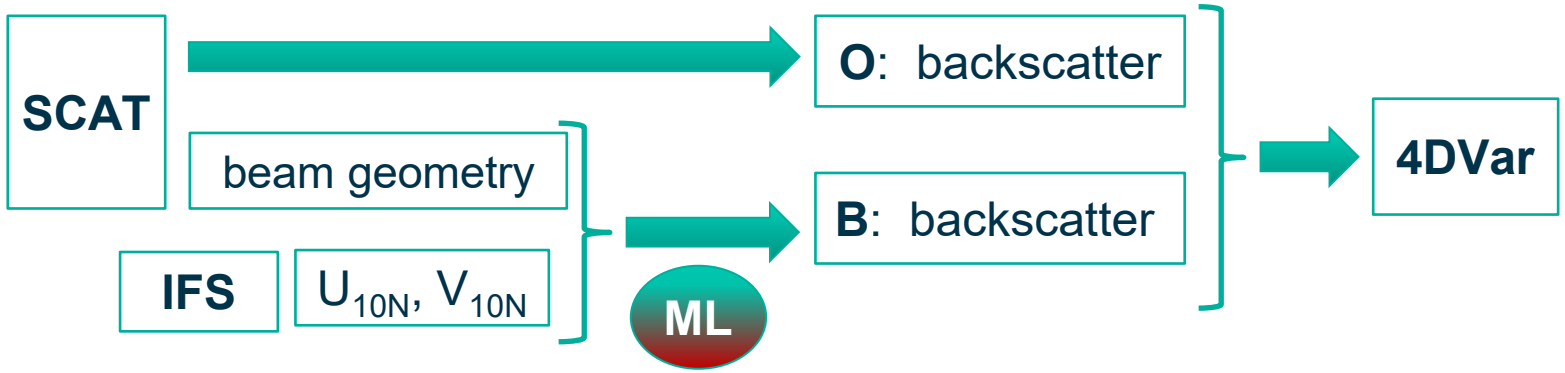
- ***Impact experiments***: Metop B+C ASCAT (other scatts not assimilated)
  - CTL (or U/V): assimilate ambiguous u/v retrievals as done in **operations** (using CMOD5.n)
  - No SCATT: remove all ASCAT data
  - OSI-SAF (KNMI) U/V: OSI-SAF (KNMI) chosen wind retrievals (same as CTL but different wind product)
  - **SIG0: assimilate ASCATs as sigma0**

ASCAT observations Data Assimilation

Current operational approach



Proposed approach

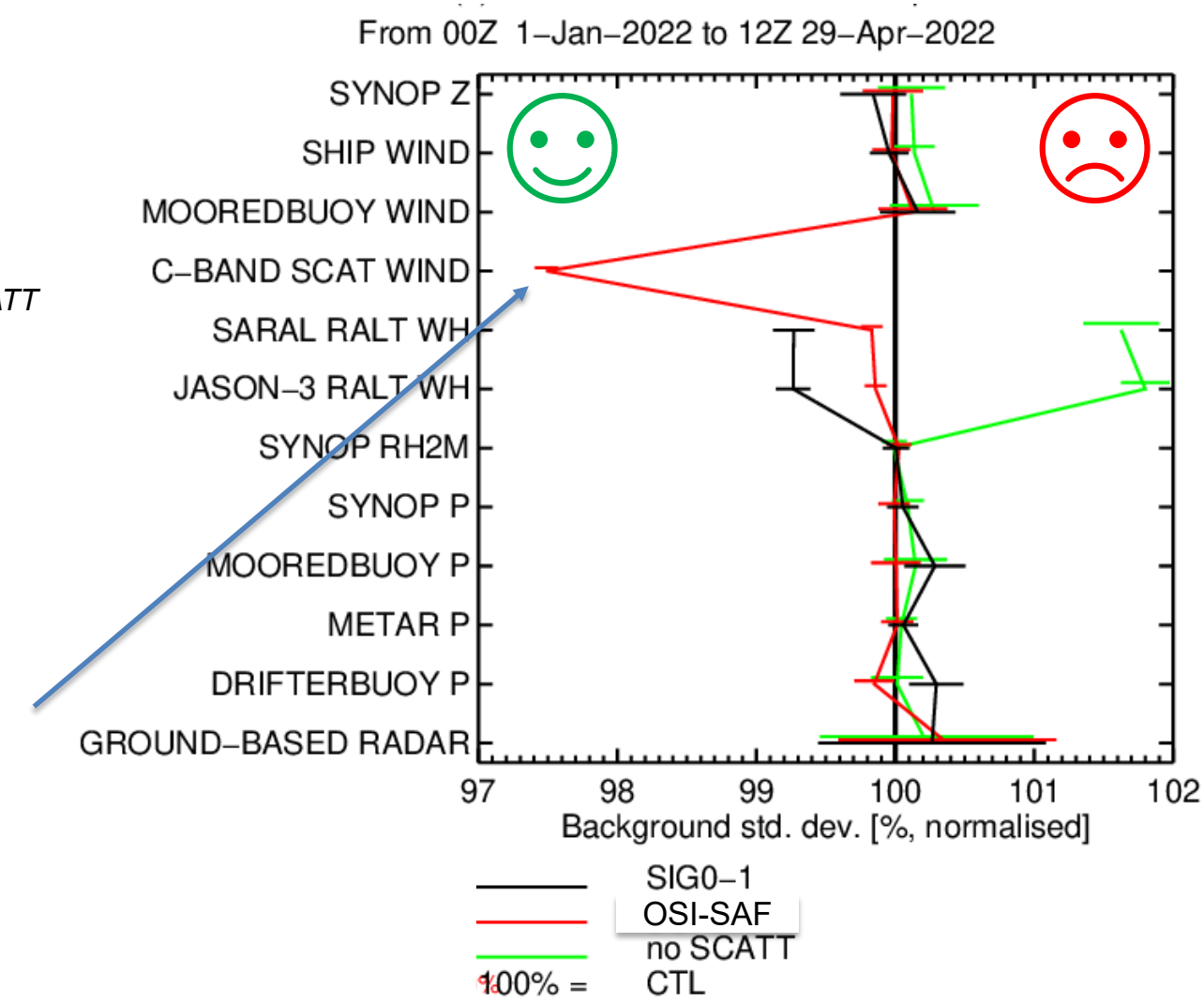


Examples of changes in short-range forecast departure statistics

Normalized SD (%) compared to CTL (U/V)

Surface observations (global)

- SCATT tends to have good impact on SWH. *Clear degradation when SCATT removed*
  (green line)
- **SIG0** seems to improve the SWH stats compared to CTL and OSI-SAF
- **SIG0** – may have some surface pressure issues
- OSI-SAF retrieved winds have better scatt departure stats than CTL:
  (o-b) reduced by more than 2 %

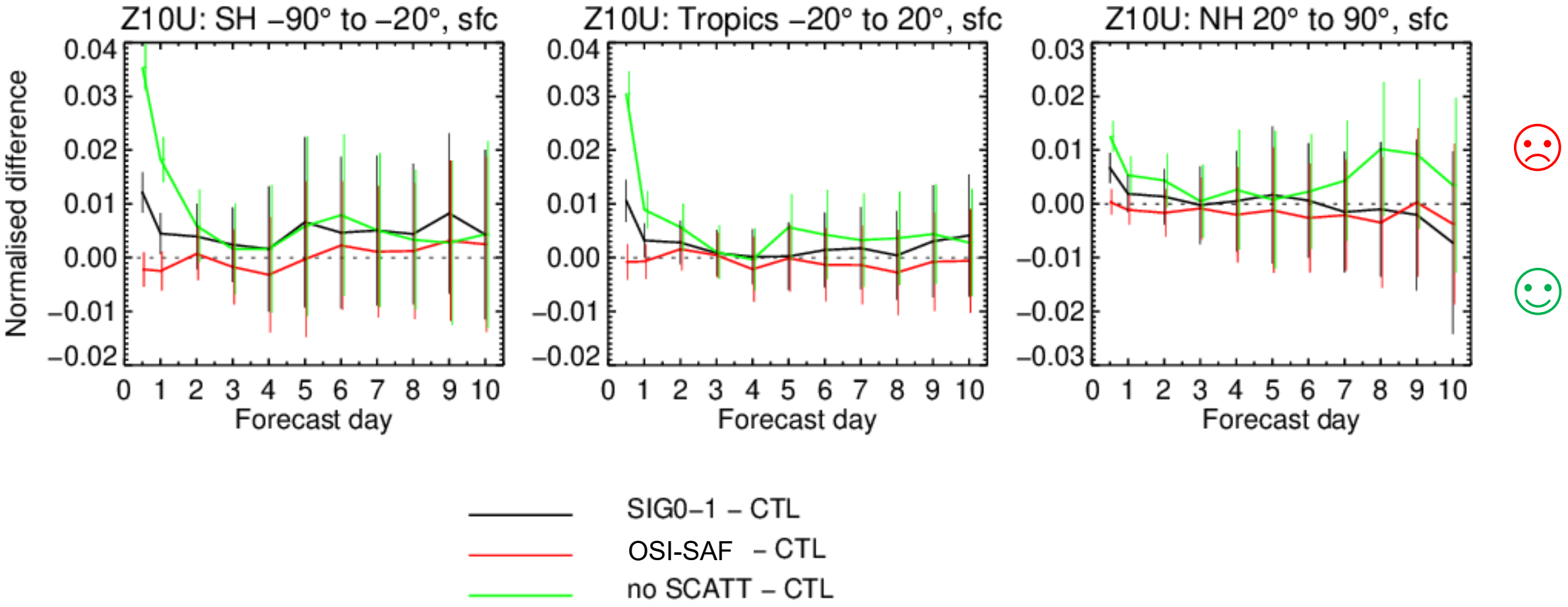


ECMWF

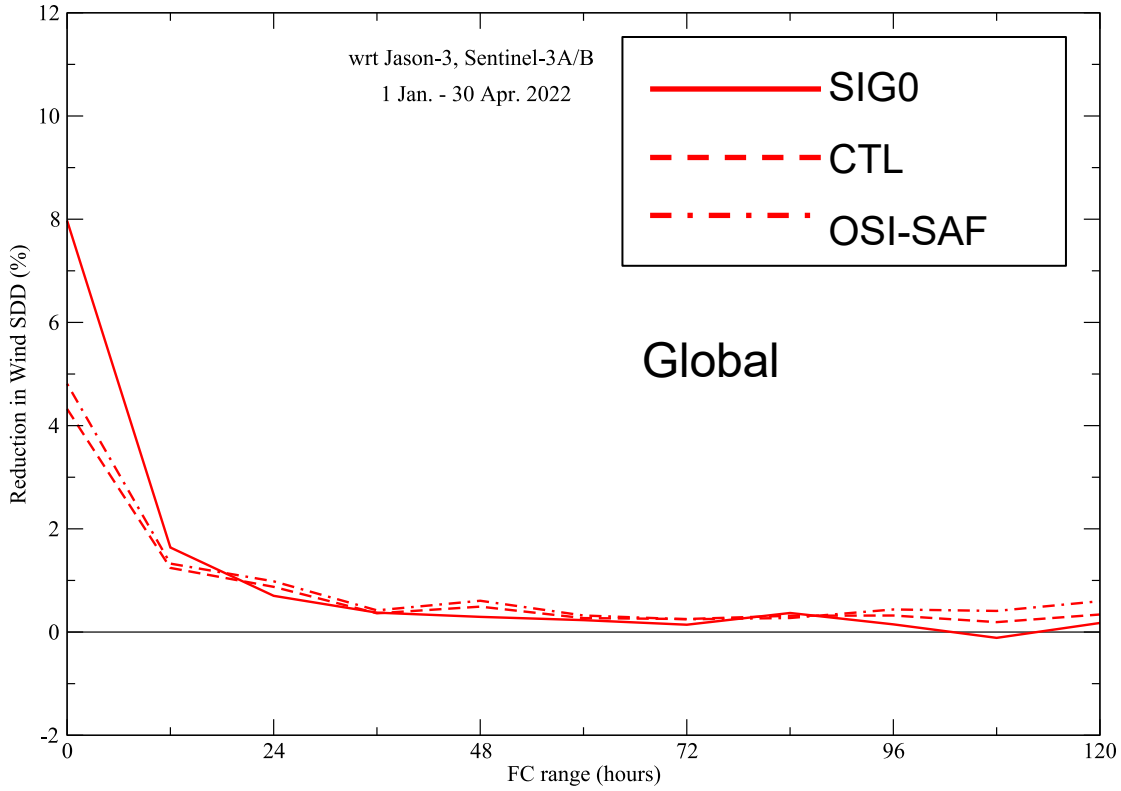
Impact on the medium-range forecast

Root mean square forecast error

U10 m winds vs operational analyses (CTL == what we do now)



Verification against altimeter 10-m wind speed



% reduction in SDD (~ random error) compared to No SCATT
(Higher is better)

Scatterometer measurements over the ocean

Important observations at the ocean interface interface

- Widely used in NWP for over 30 years, assimilated as wind vector
- Positive impact on analysis and the forecast in the atmosphere and ocean waves
- Global scale and extreme events
- In couple systems the impact on the ocean parameters is seen down to the thermocline (-300m)
- Ocean currents have an impact on the scatt assimilation

Can we get closer to what a scatterometer actually measures assimilating backscatter?

- Results suggest that the backscatter assimilation is *viable*
- Very encouraging results but not “perfect” yet: some forward model issue at high winds, winds not turning as well as using U/V around TC
- In a coupled system, tests on including ocean parameters in the ML forward model could be done

At ECMWF used in operations and in the Reanalysis

- In **operations** currently using: ASCAT-A/B/C; HY-2B (HY-2C/D active within 2 weeks!)
- Soon testing Oceansat-3
- Soon starting the preparation for SCA-EPS-SG: OSI SAF L2 winds will be considered instead on in-house wind inversion

- In **ERA6:** ERS1/2, QuikSCAT, ASCAT-A/B/C and HY-2B/C/D will be used in *ERA6*
- Any new datasets added to oper will be (possibly) used in ERA6 with a little delay