Sea-state dependency of air-sea fluxes in ECMWF Earth System Model

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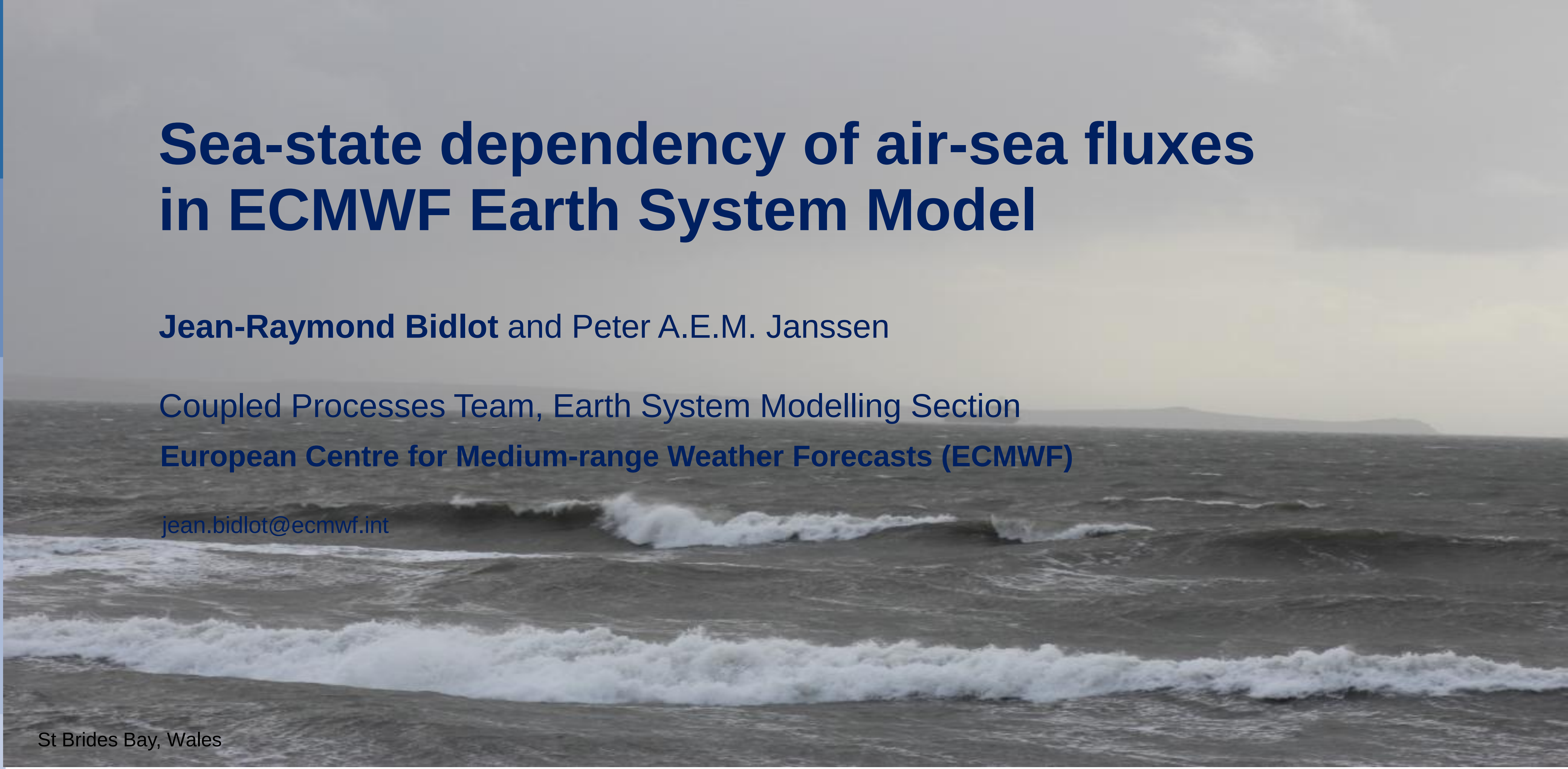
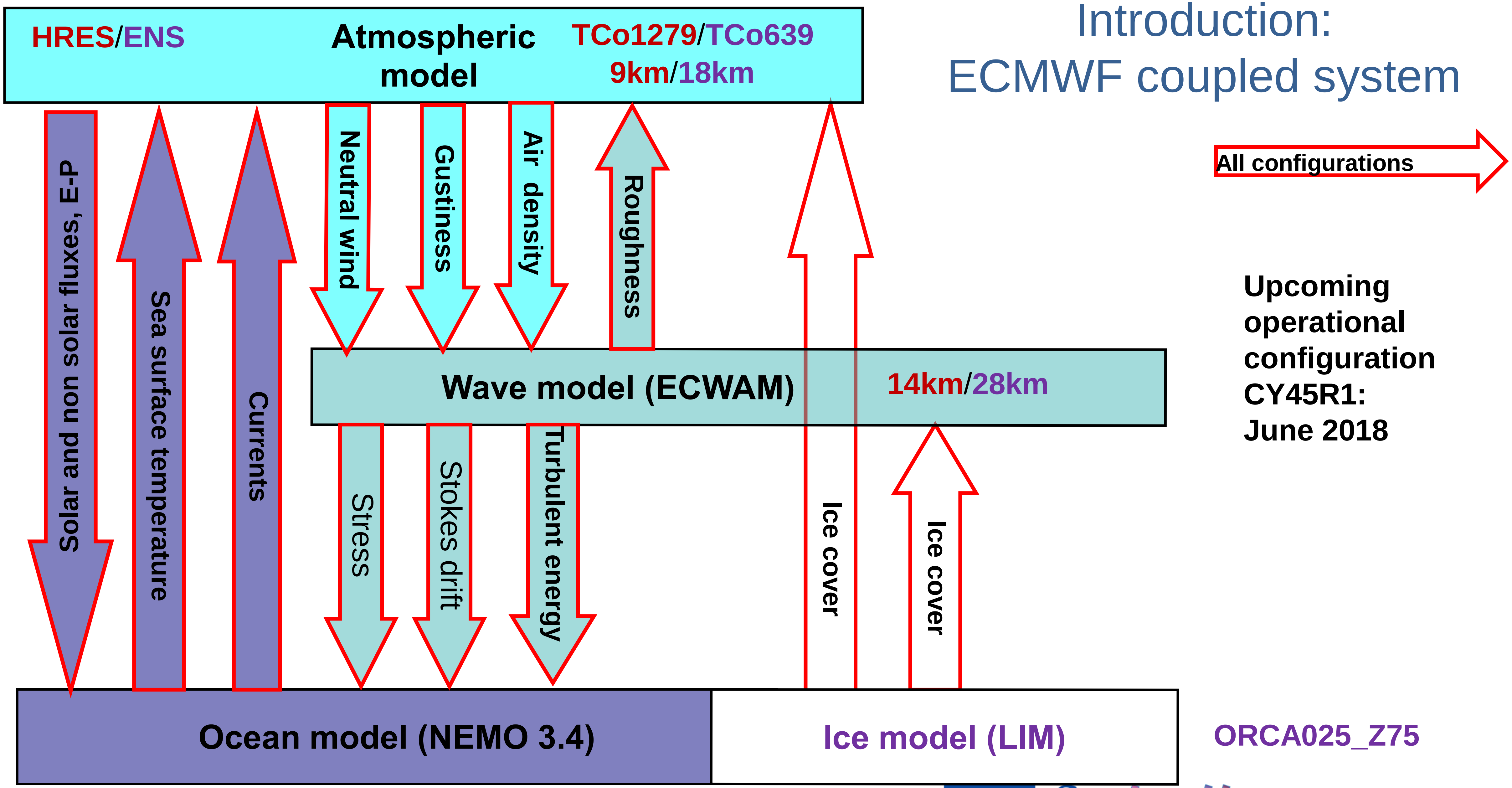


St Brides Bay, Wales

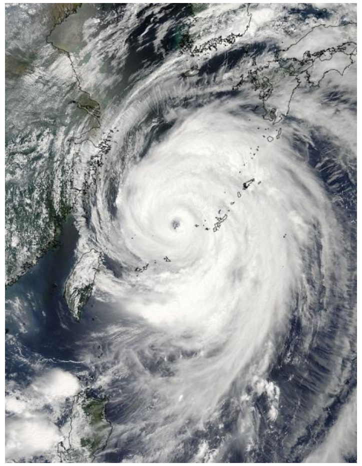
Introduction:
ECMWF coupled system



Upcoming operational configuration CY45R1: June 2018

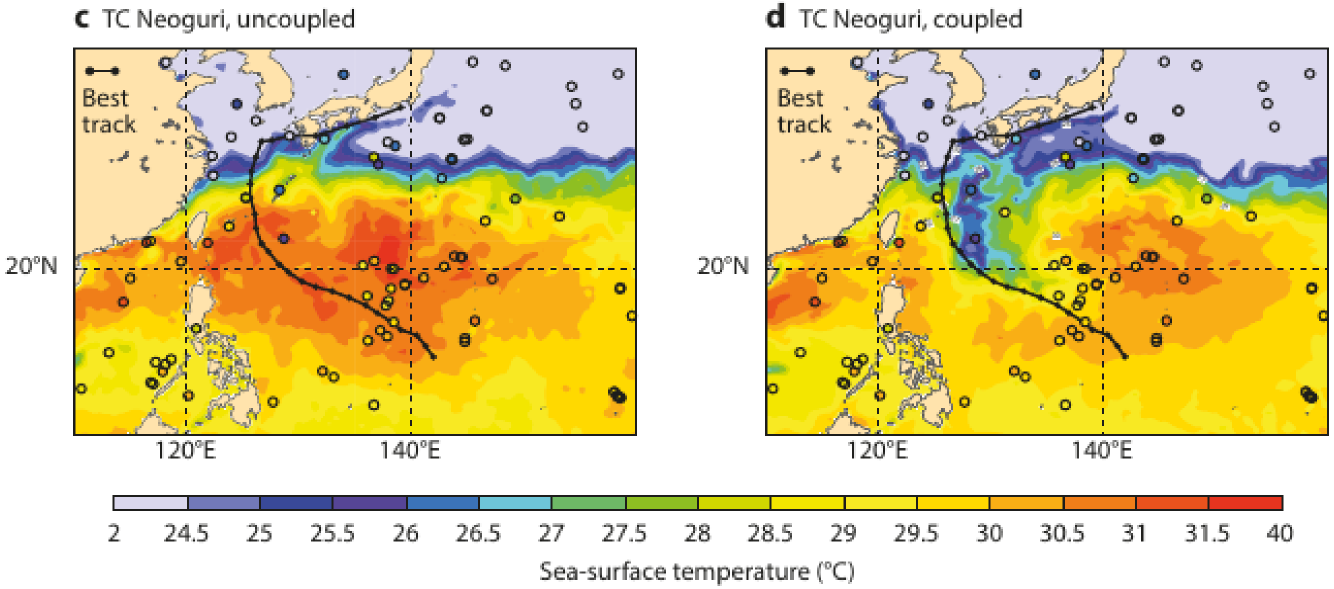
ORCA025_Z75

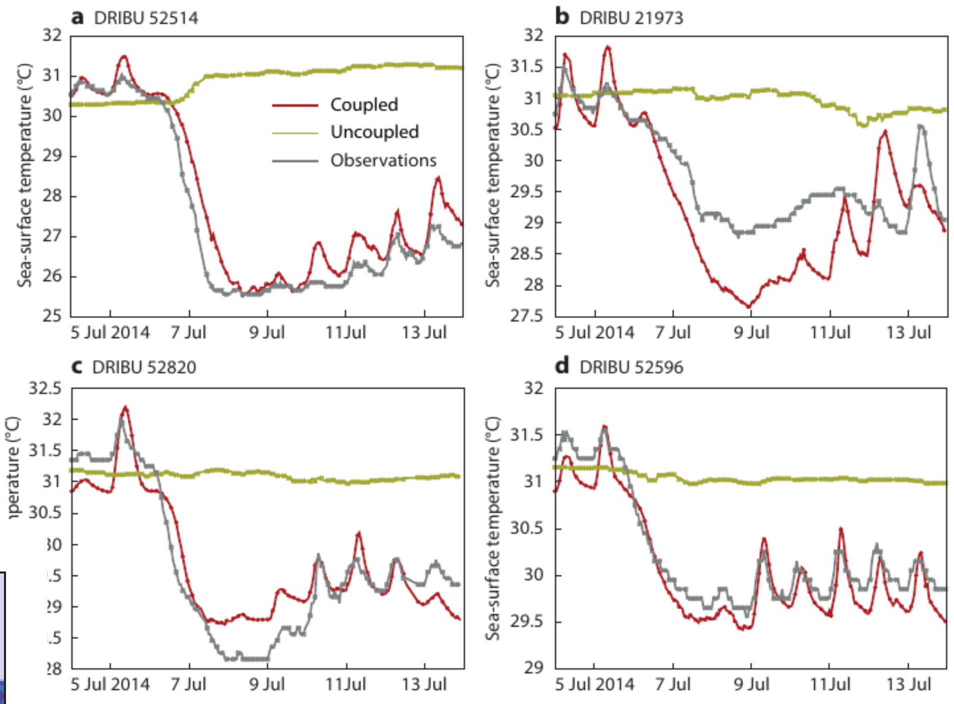
Coupling on tropical cyclone forecast: reduction of intensity error and realistic ocean response



Neoguri affecting Okinawa on July 8, 2014

Mogensen et al. 2017





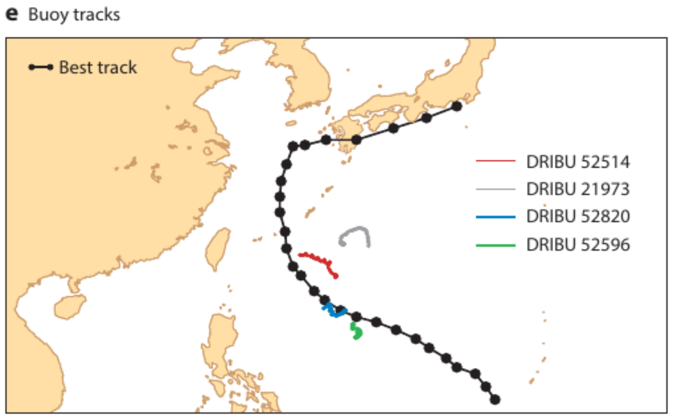
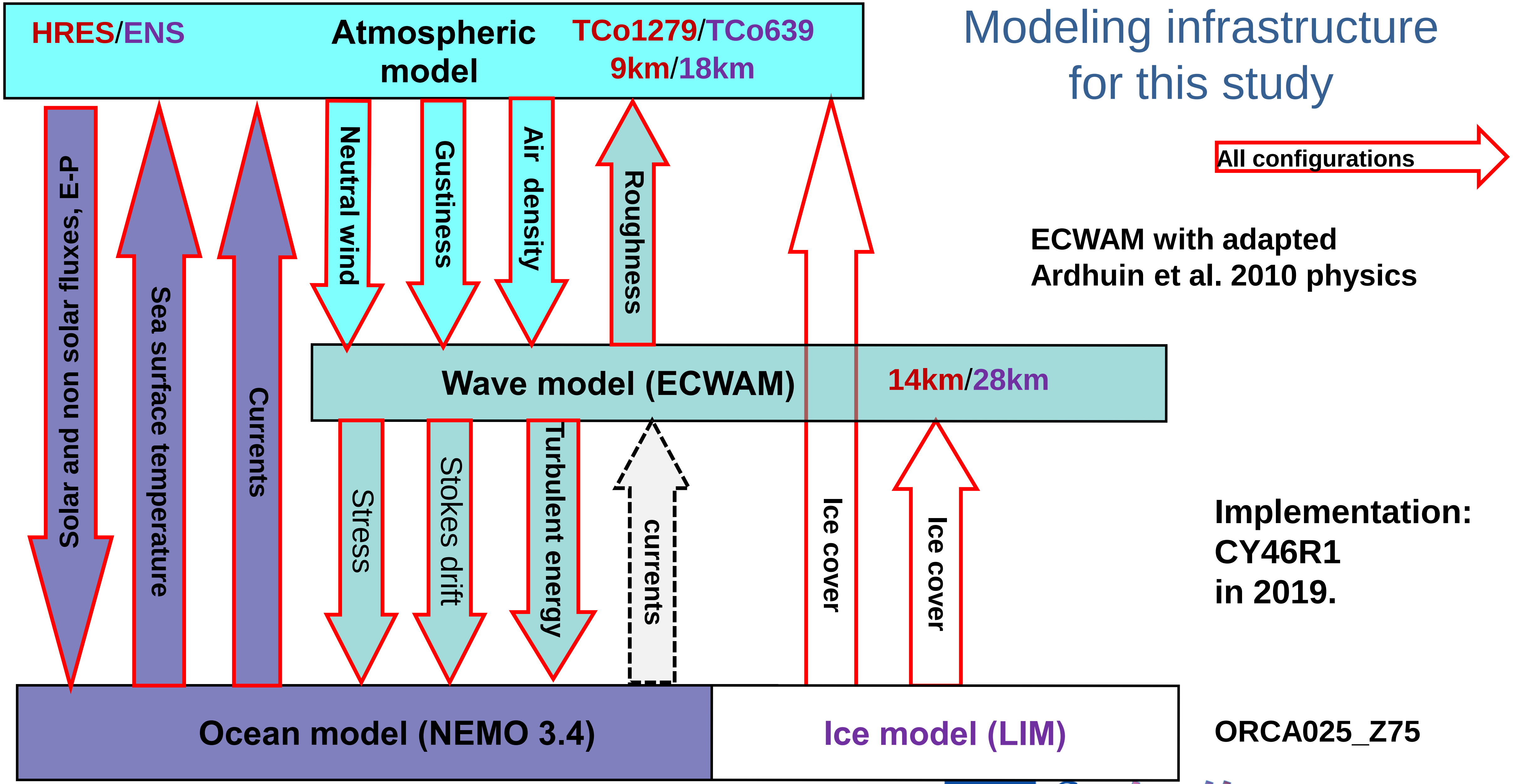


Figure 4
Observations from four DRIBU buoys and SST forecasts starting on 4 July for the same locations in the Neoguri case for (a) DRIBU 52514, (b) DRIBU 21973, (c) DRIBU 52820 and (d) DRIBU 52596, along the tracks shown in (e).

Modeling infrastructure for this study

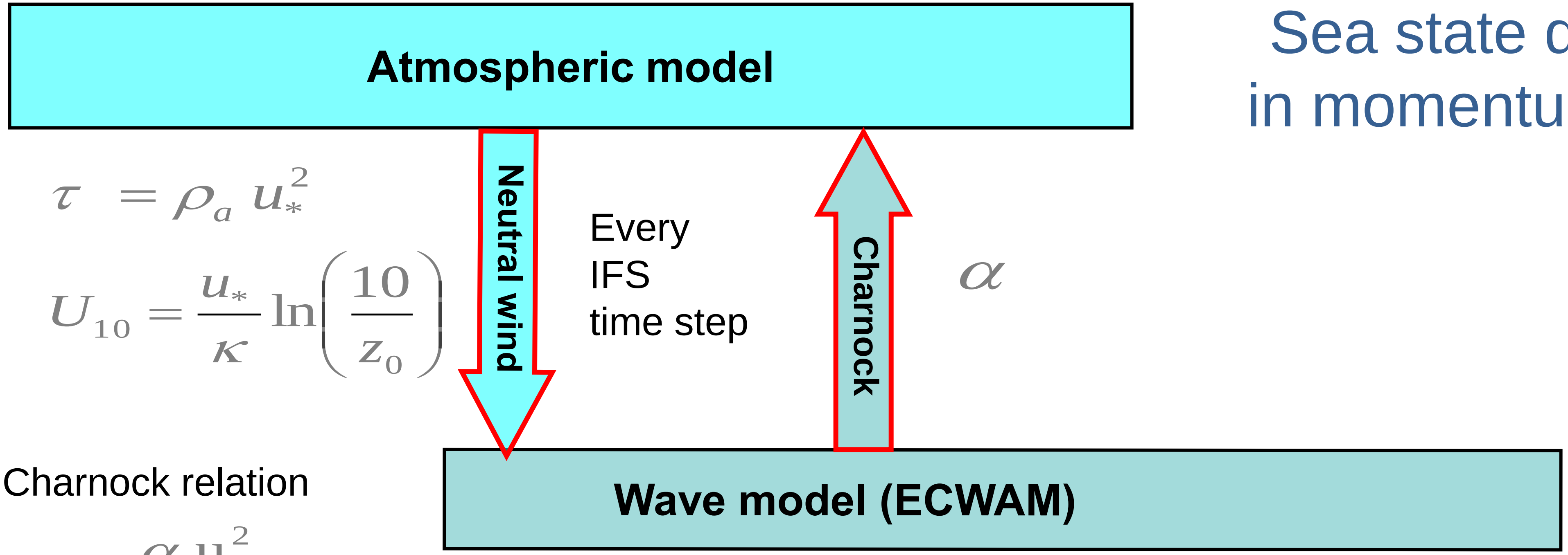


ECWAM with adapted Ardhuin et al. 2010 physics

Implementation:
CY46R1
in 2019.

ORCA025_Z75

Sea state dependency in momentum exchange



$$\tau = \rho_a u_*^2$$

$$U_{10} = \frac{u_*}{\kappa} \ln\left(\frac{10}{z_0}\right)$$

Charnock relation

$$z_0 = \frac{\alpha\, u_*^2}{g}$$

α is sea state dependent

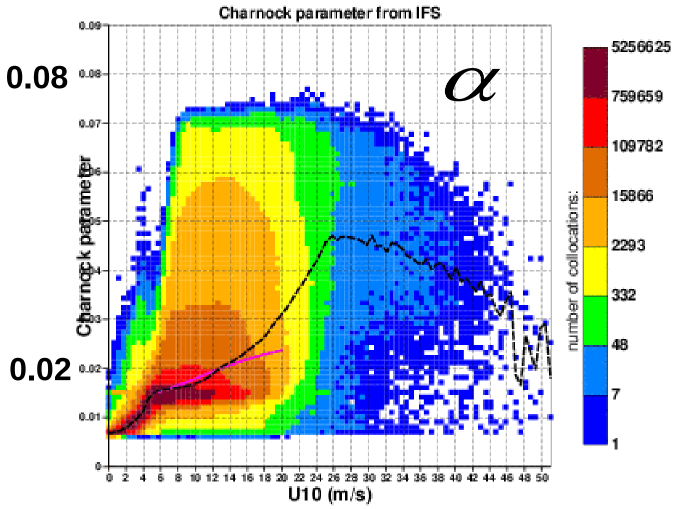
$$\alpha = \frac{\tilde{\alpha}}{\sqrt{1 - \frac{\tau_w}{u_*^2}}}$$

$\tilde{\alpha}$ minimum Charnock

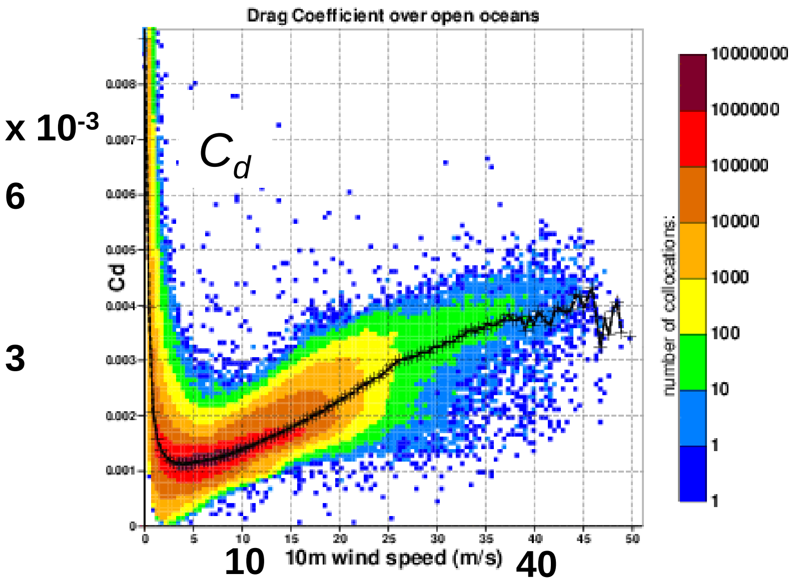
Wave induced stress:
Momentum flux generating waves

$$\tau_w = \frac{\rho_w}{\rho_a} g \int d\omega\, d\theta\, \frac{1}{c} S_{in}$$

S_{in} : source term for the input of wind into waves

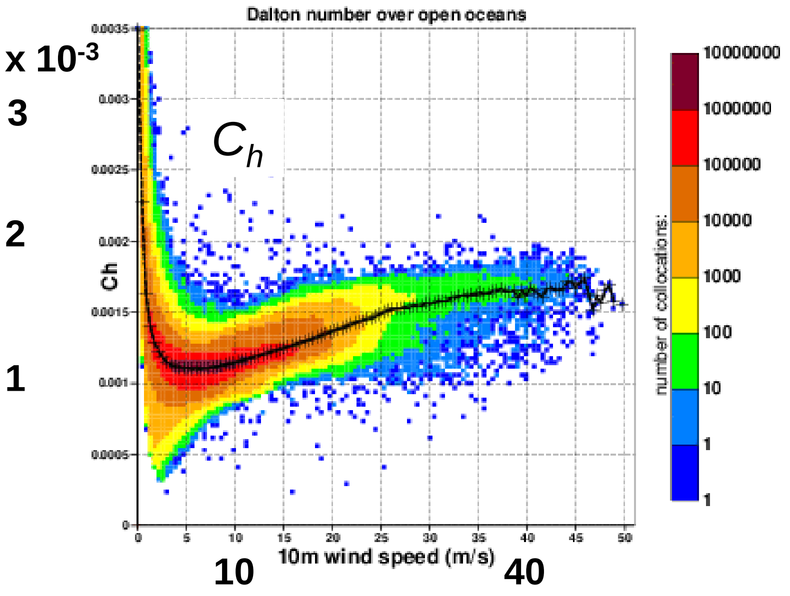


Sea state dependency on momentum and heat fluxes



Exchange coefficients dependency on wind speed
Left: for momentum (C_d)
Right: for heat (C_h)

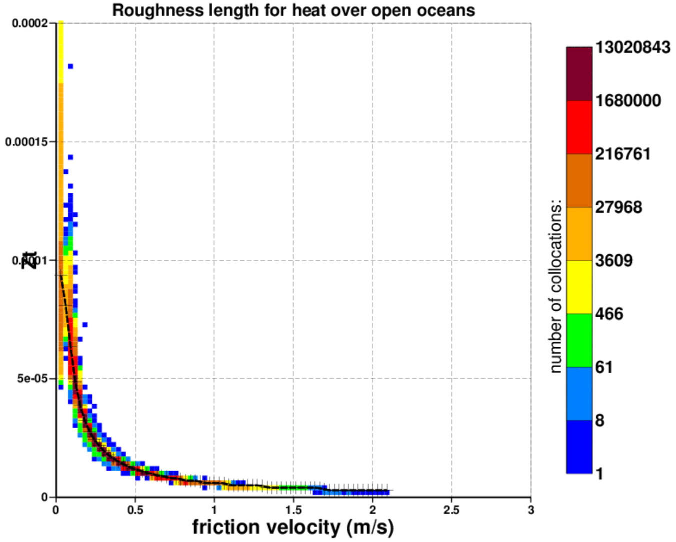
Forecast from 20170905
t=6 to 240 by 6
All open ocean grid points.



C_d is sea state dependent

$$\tau = \rho_a C_d U_{10}^2$$

Z_T



TCo1279 forecast
gwno from 20170817 step 6 to 240 by 6

$$C_h = C_d^{1/2} \frac{\kappa}{\ln(\frac{10}{z_T})}$$

$$z_T = z_\nu = \delta \frac{\nu}{\kappa u_*}$$

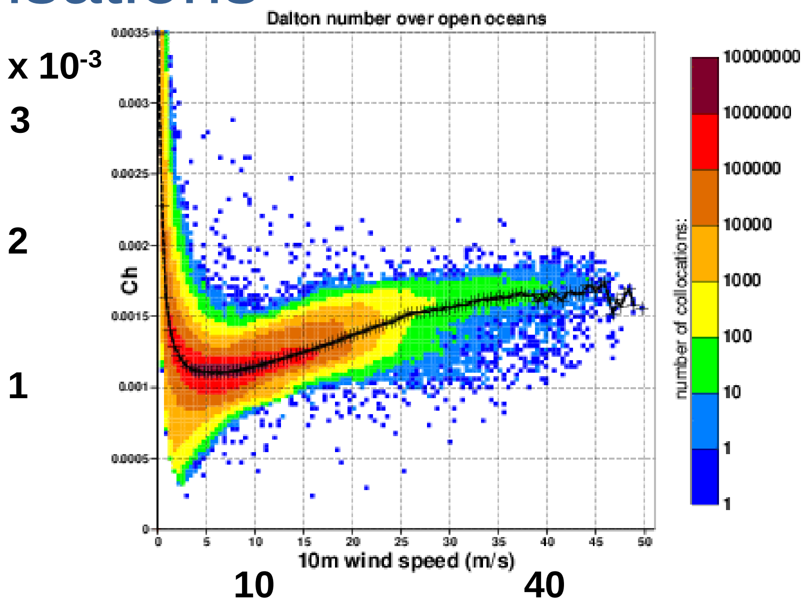
δ adjustable parameter

Current operational system

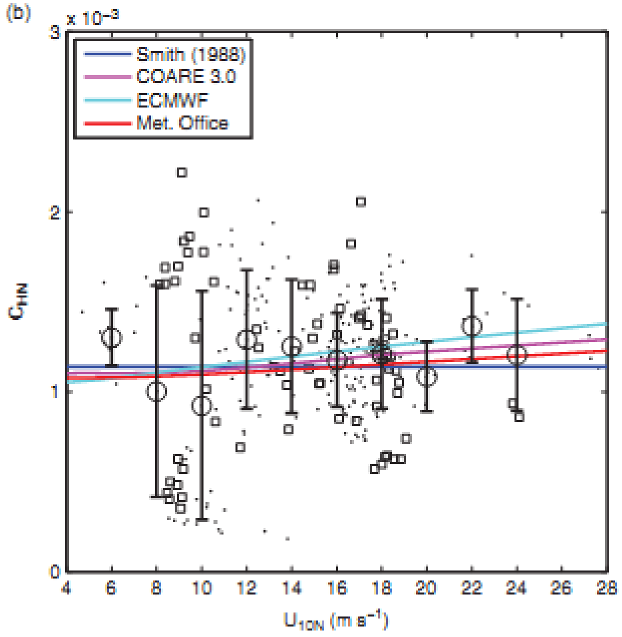
ECMWF

Impact of Coupling: revisit parameterisations

Exchange coefficients dependency on wind speed
Right: for heat (Ch)



The current model is underestimating a bit the heat transfer from the surface .



Cook and Renfrew 2014

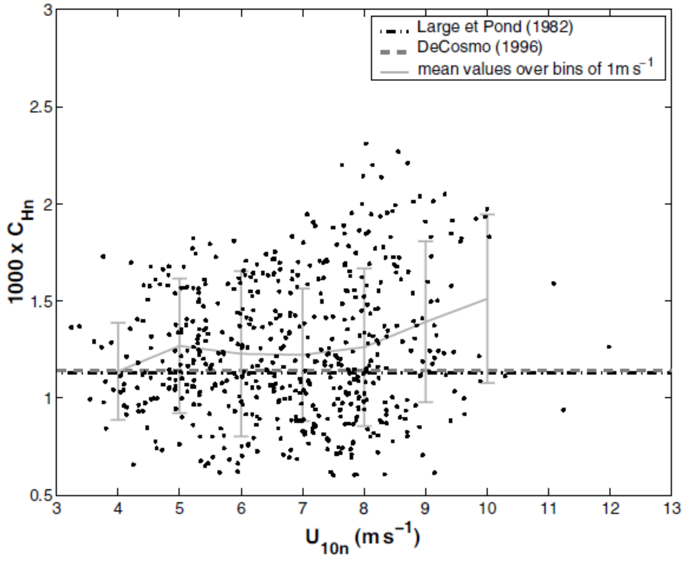


Figure 18. The exchange coefficient for temperature, C_{Hn}, as a function of the neutral wind speed at 10 m, U_{10n}. The dots correspond to 30-minute samples. The solid line with error-bars represents the values averaged over wind speed bins of 1 m s^{-1}. The parametrizations proposed by Large and Pond (1982) and DeCosmo *et al.* (1996) are also plotted.

Brut et al. 2005

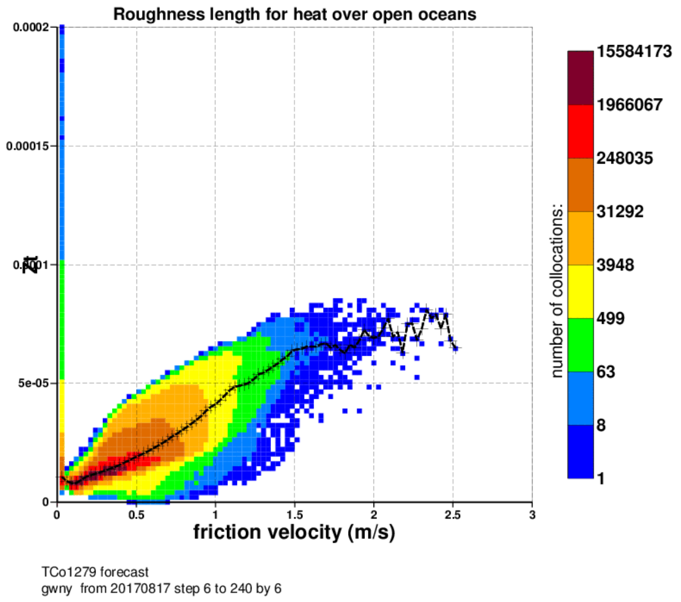
Effect of waves on heat flux : Janssen 1997

$$z_T = 10^{\dfrac{\left(\frac{10+x_-}{x_-}\right)^{(z_1 - x_-)}}{\left(\frac{10+x_+}{x_+}\right)^{(z_1 - x_+)}}}$$

$$x_\pm = (z_1 + \tfrac{1}{2} z_\nu) \mp \{z_1^2 + (\tfrac{1}{2} z_\nu)^2\}^{1/2}$$

$$z_1 = \frac{u_*^2}{g}(\alpha - \tilde{\alpha}) \qquad z_\nu = \frac{\delta \nu}{\kappa u_*}$$

z_T

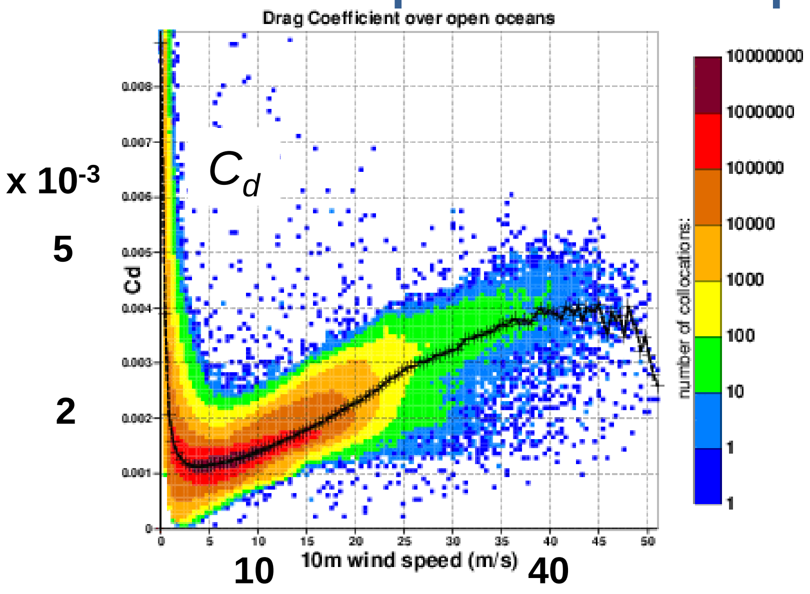


α Sea State dependent Charnock

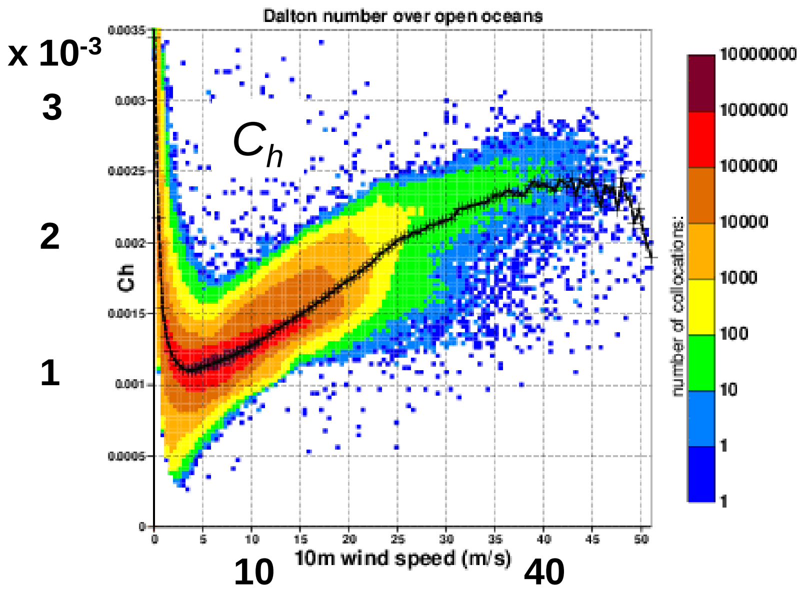
$\tilde{\alpha}$ minimum Charnock

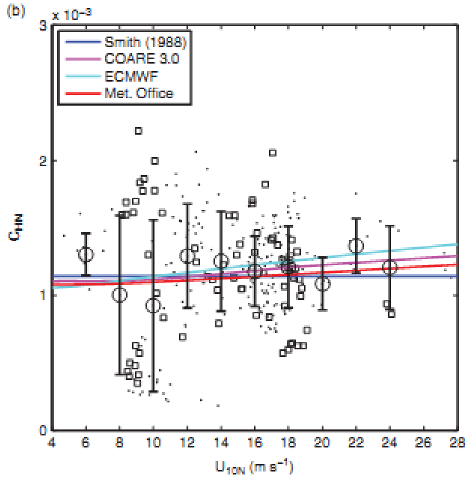
Janssen, P.A.E.M., 1997: Effect of surface gravity waves on the heat flux. ECMWF Technical Memorandum 239. http://www.ecmwf.int/en/elibrary/technical-memoranda

Impact of Coupling: revisit parameterisations

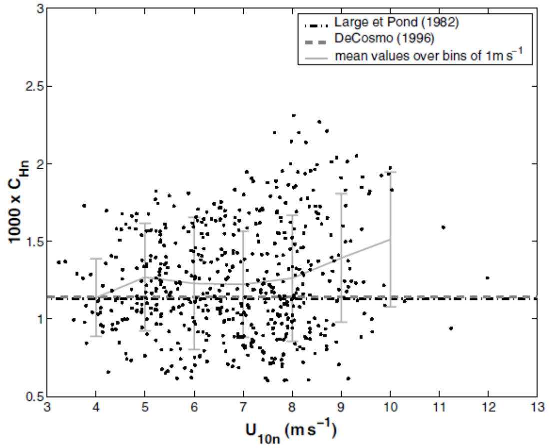


Heat exchange coefficients dependency on wind speed





Cook and Renfrew 2014



Brut et al. 2005

Similarly for moisture flux

Impact of Coupling on tropical cyclone forecast

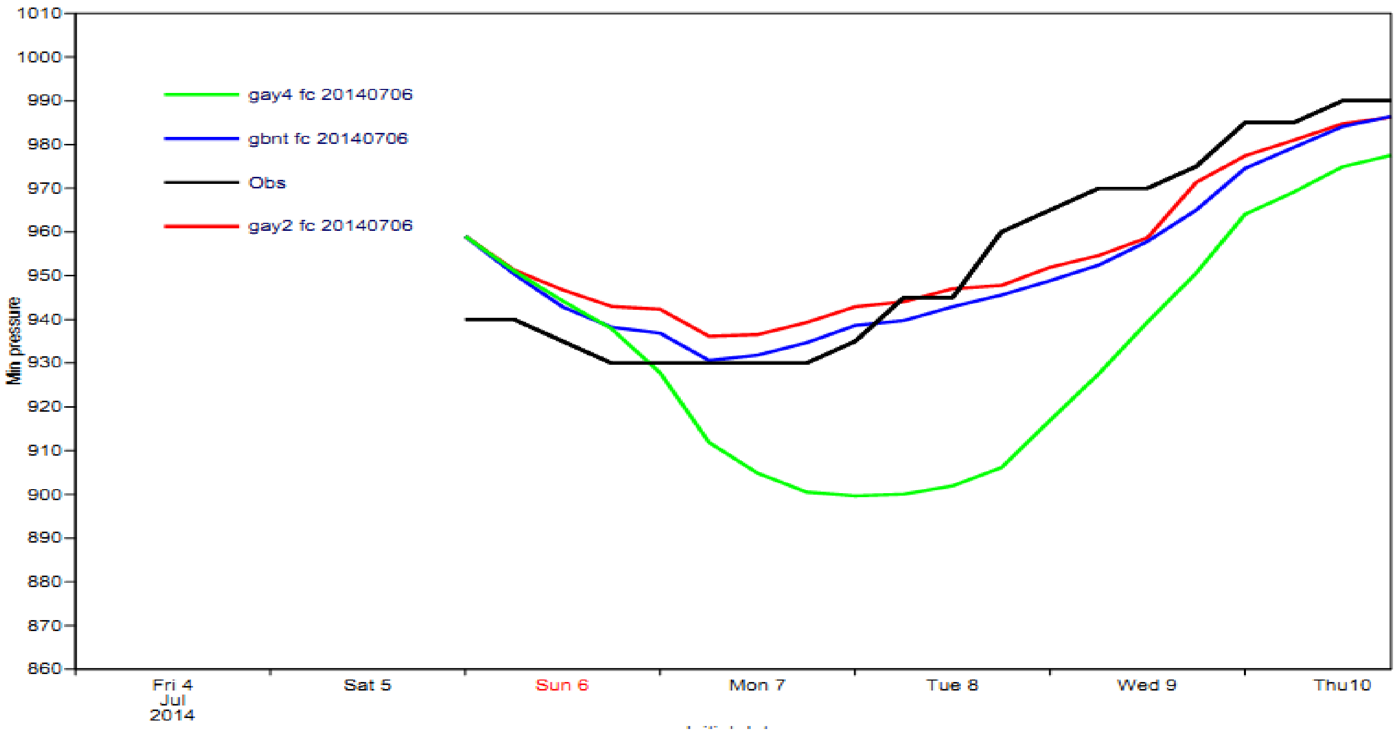
Mean Sea Level Pressure (hPa),

Neoguri

.

950

900

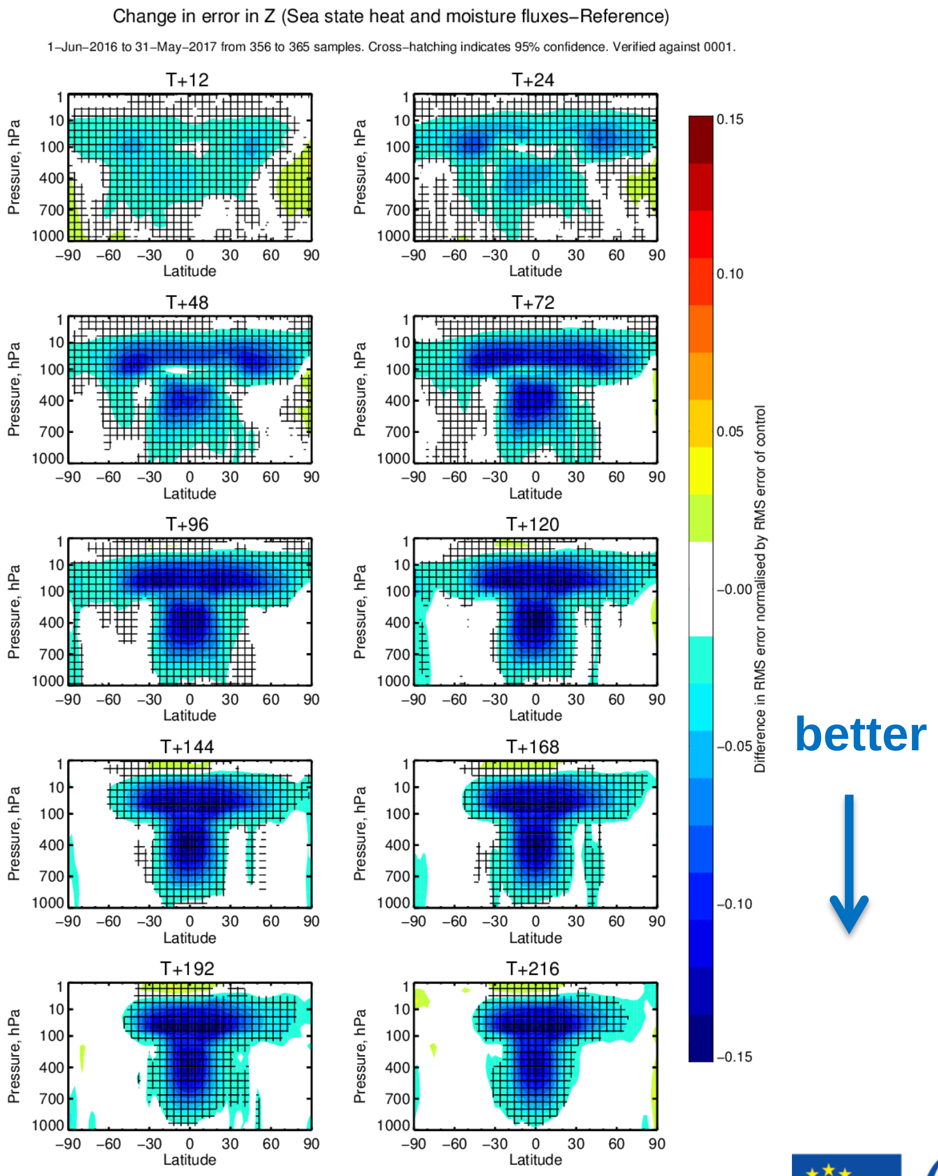


Black: estimated from observations
Green: operational HRES configuration (**uncoupled**) (16km)
Red: 16km **coupled** to NEMO (ORCA025_Z75)
Blue: 16km **coupled to NEMO + new sea state dependant heat and moisture fluxes**

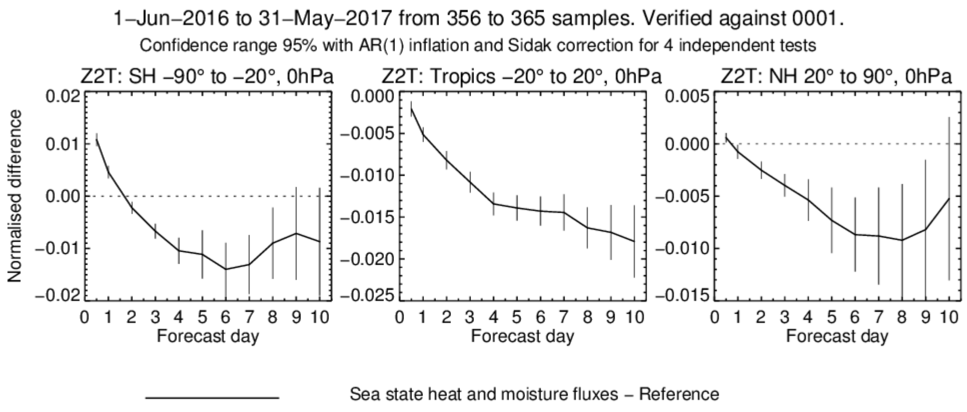
Sensitivity study: wave dependent heat and moisture fluxes

<u>Forecast only experiments</u>
(8 months)

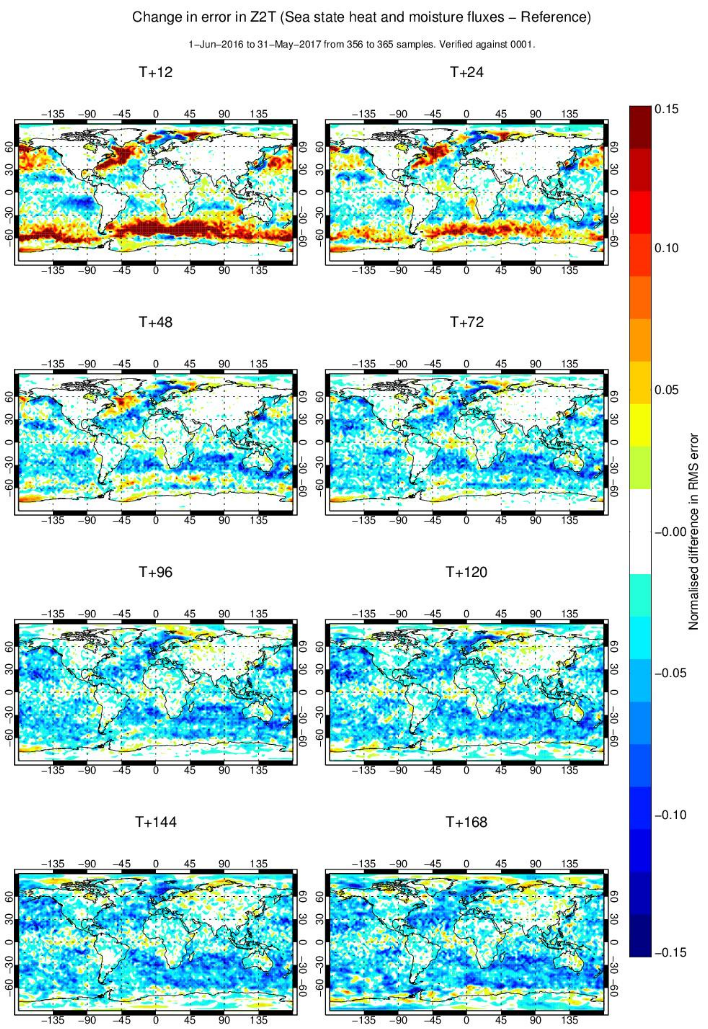
Normalised difference in RMSE for geopotential height (Z)
against operational analysis.
new – default



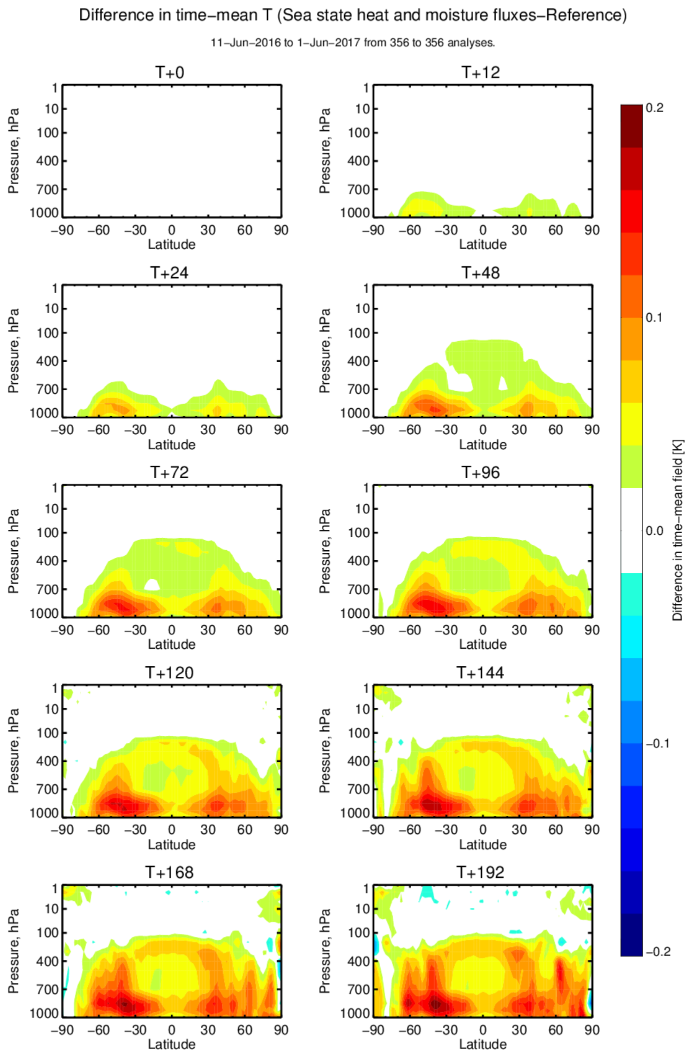
Sensitivity study: wave dependent heat and moisture fluxes



Normalised difference in RMSE for 2mT



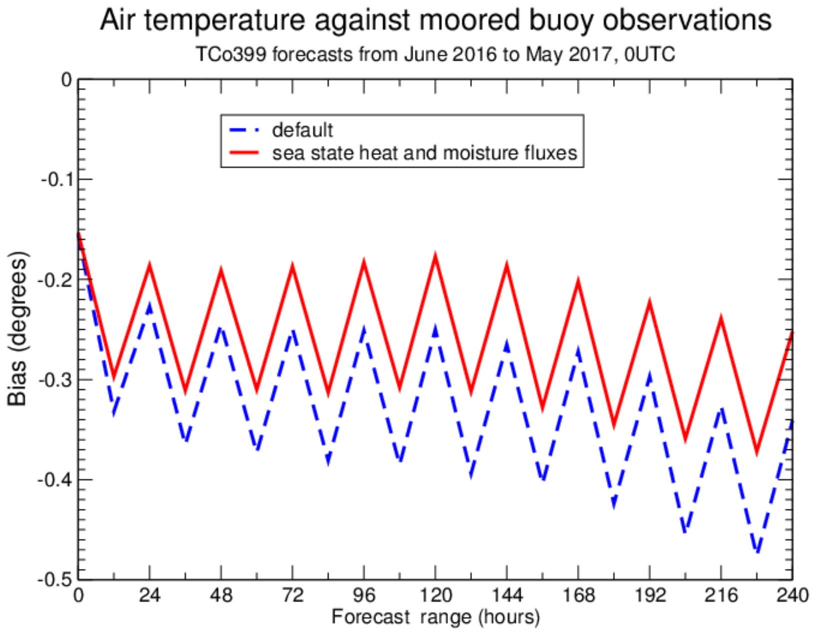
Normalised difference in RMSE for 2mT

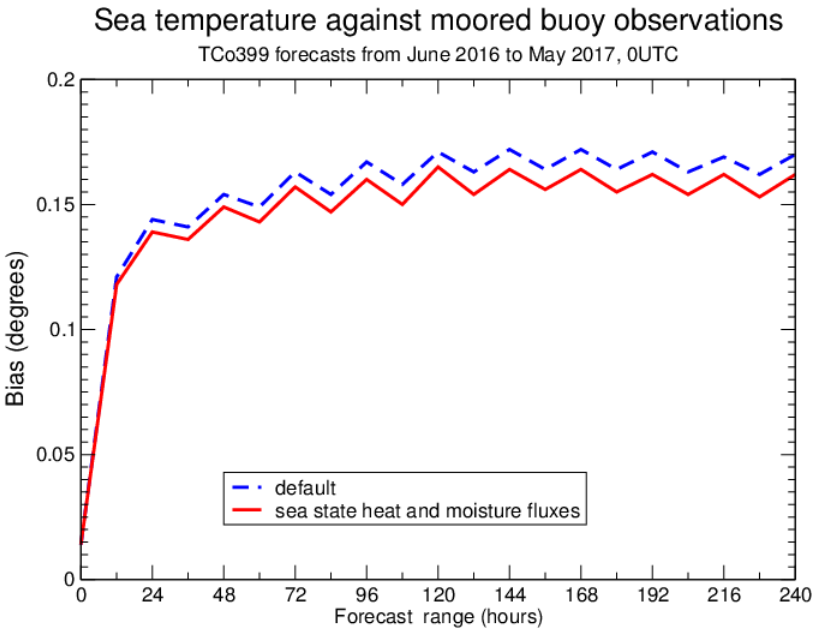


Mean forecast difference in T

Sensitivity study: wave dependent heat and moisture fluxes

Bias





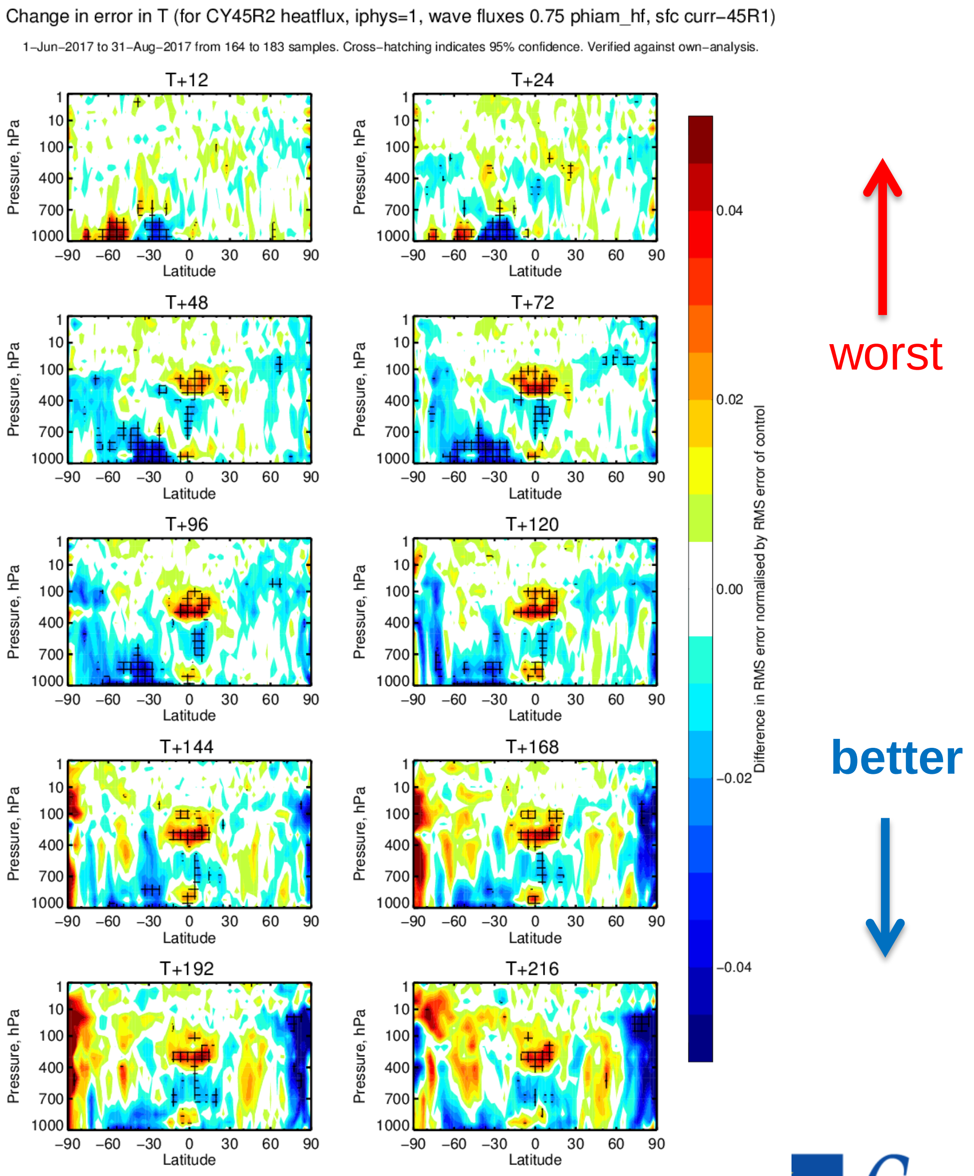
Tair

Tsea

Problem with experiment with data analysis (i.e. analysis + forecasts):

<u>Analysis and Forecast experiments</u> (3 months)

Normalised difference in RMSE for Temperature (T) against <u>own</u> analysis.
new – default



Need the tangent linear and the adjoint for the expression of z_T

Simplification needed to derive the tangent linear and the adjoint:

$$z_\nu = \frac{\delta \nu}{\kappa u_*}$$

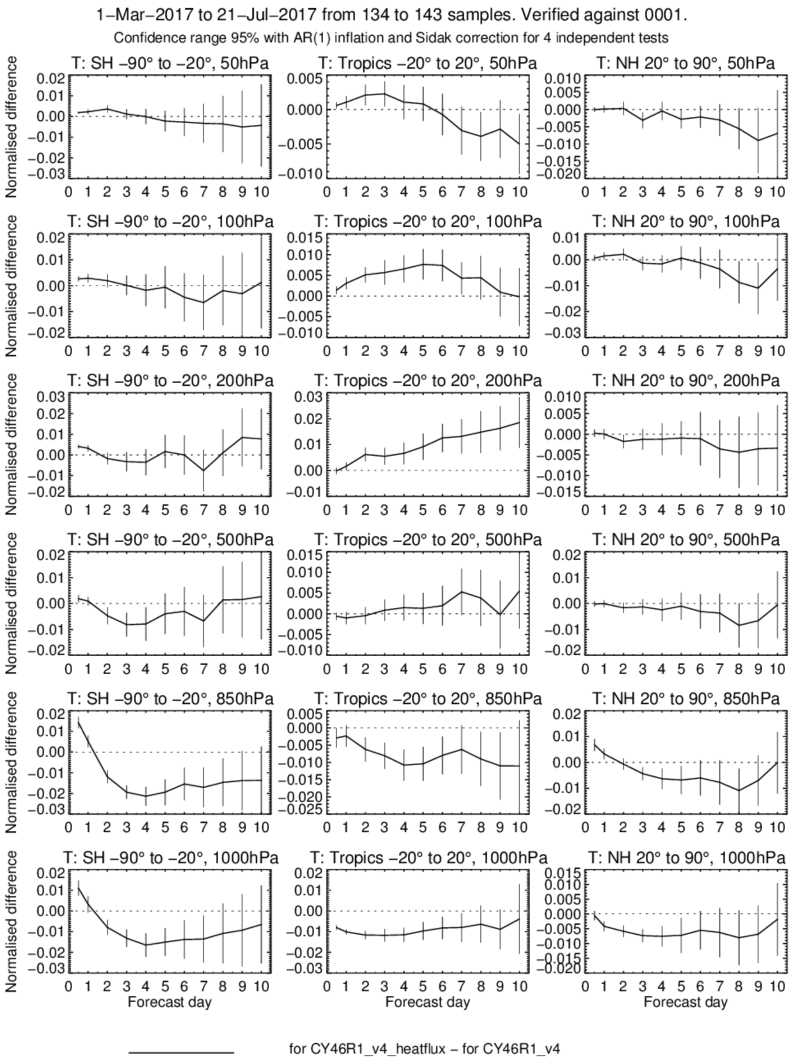
$$z_T = \sqrt{z_\nu \left(z_\nu + z_1\right)}$$

$$z_1 = \frac{u_*^2}{g}(\alpha - \tilde{\alpha})$$

Sensitivity study: forecast only: OK

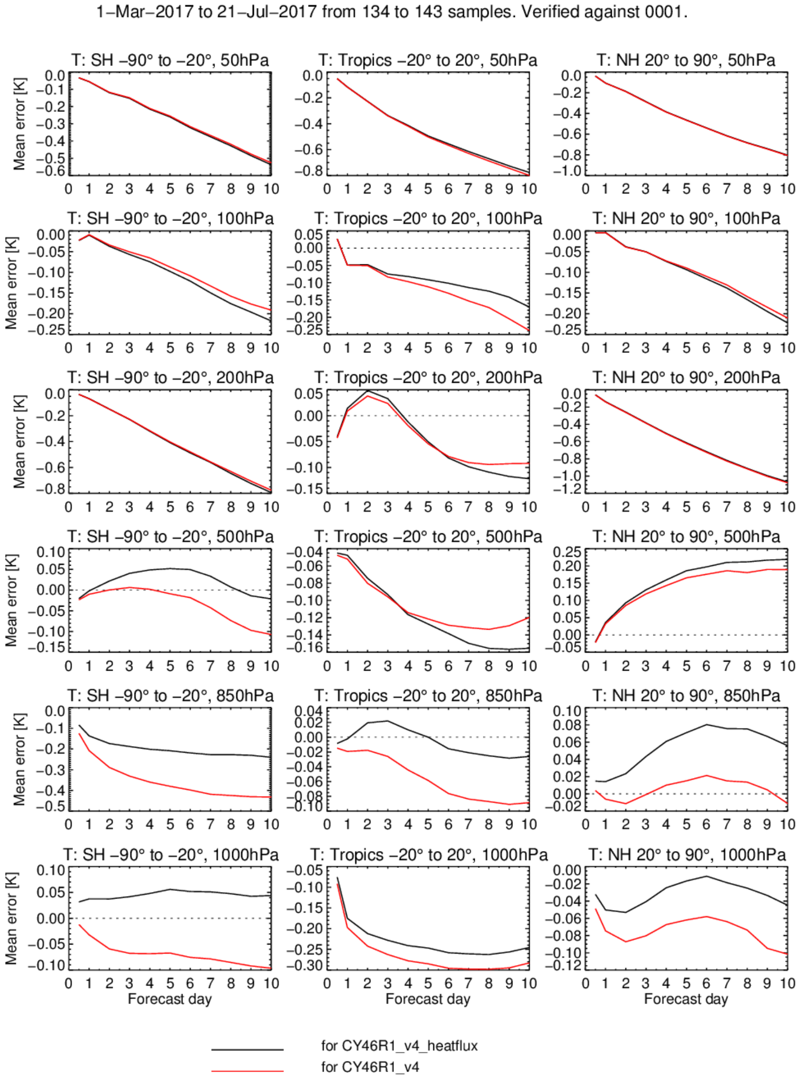
<u>Forecast only experiments</u> (5 months)

Normalised difference in RMSE for Temperature (T) against operational analysis.
new – default



<u>Forecast only experiments</u> (5 months)

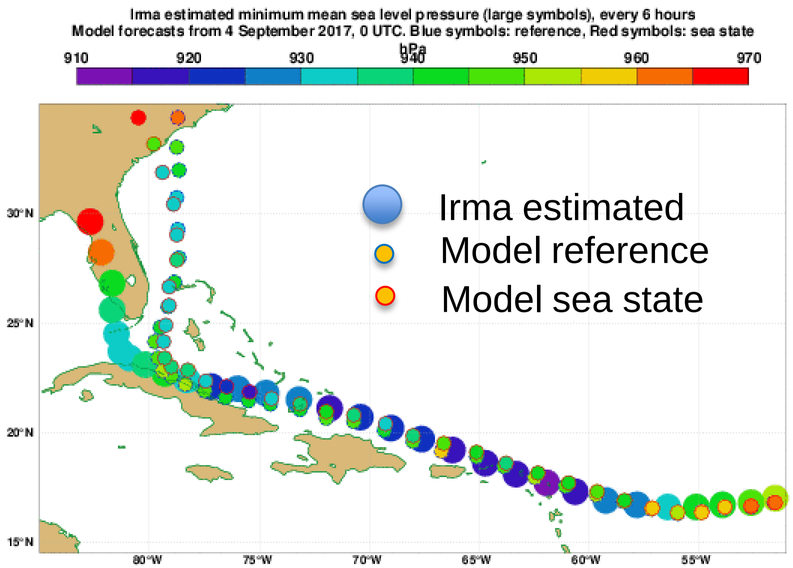
Mean error in Temperature (T) against operational analysis.
new – default

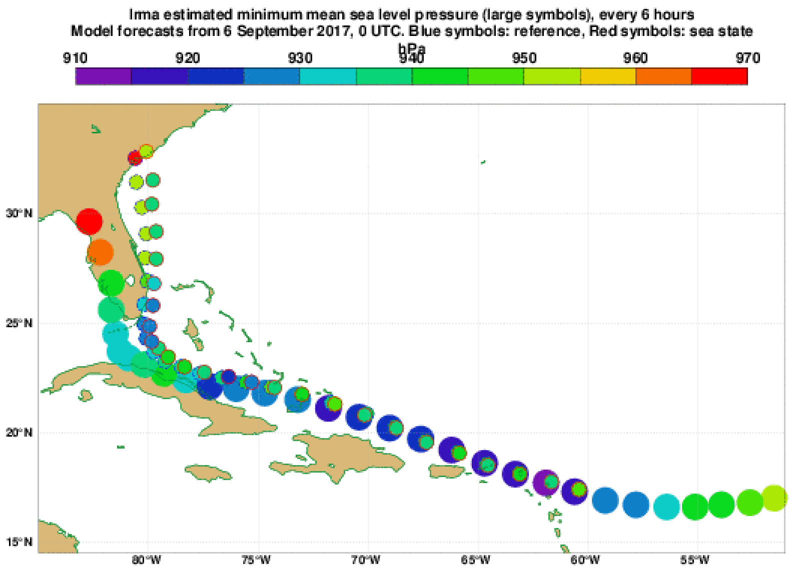


Sensitivity study: Hurricane Irma

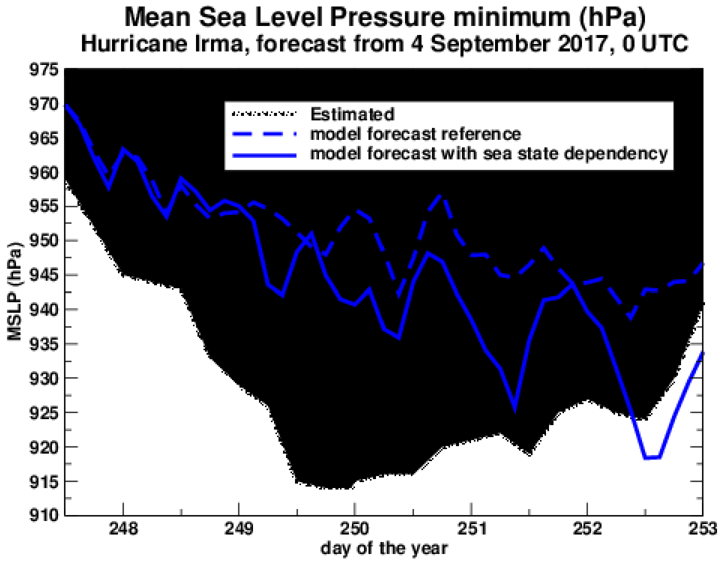
Mean Sea Level Pressure (hPa), every 6 hours.

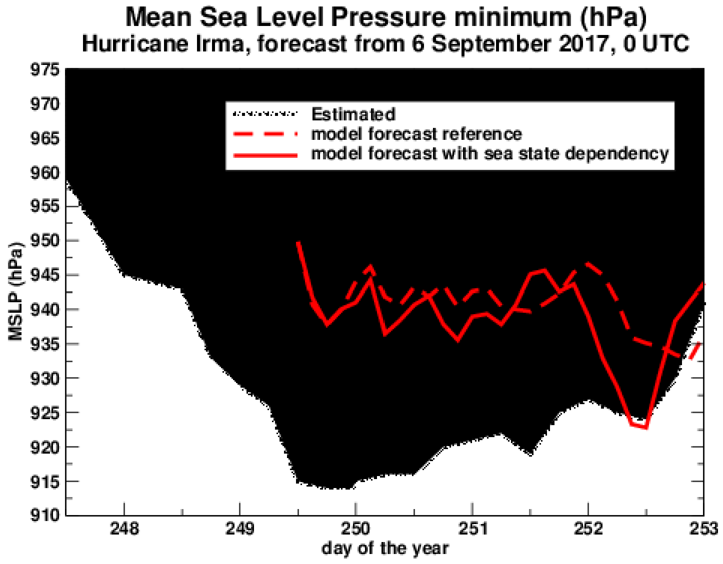
Forecast from 4 September, 2017, 0 UTC.





Forecast from 6 September, 2017, 0 UTC.





Conclusions:

- ECMWF has a fully coupled atmosphere-wave-ocean circulation operational forecasting system.
- There is a clear benefit in coupling the different models, but it creates new challenges as model parameterisations will need revisiting and new processes might need to be added (e.g. impact of sea sprays).
- We are testing a new parameterisation that includes a direct effect of sea state to the heat and moisture transfer from the ocean surface.
- Results of forecasts only experiments are promising.
- Analysis experiments are been carried out.

Thank you for your attention …

Janssen, P.A.E.M., 1997: Effect of surface gravity waves on the heat flux. ECMWF Technical Memorandum 239. http://www.ecmwf.int/en/elibrary/technical-memoranda

Janssen, P.A.E.M and J-R Bidlot, 2018: Progress in Operational Wave Forecasting. IUTAM Symposium Wind Waves, 4-8 September 2017, London, UK.

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Wu, L., Rutgersson, A., Sahlée, E., and Larsén, X., 2015: The impact of waves and sea spray on modelling storm track and development. Tellus, 67. doi:10.3402/tellusa.v67.27967.