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

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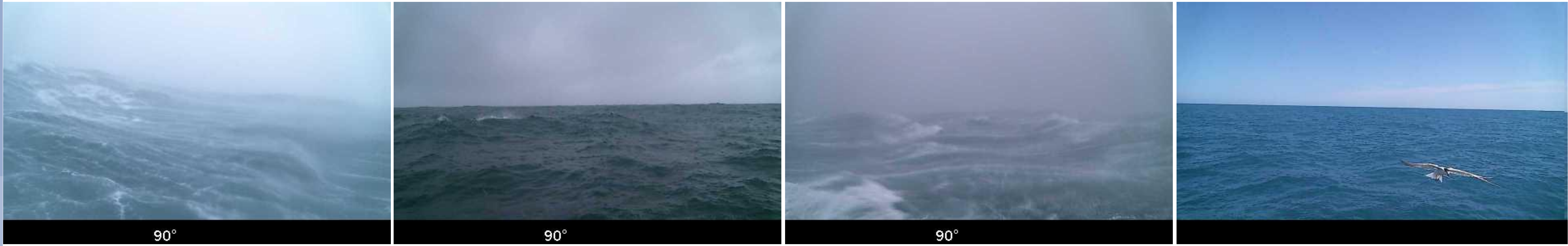
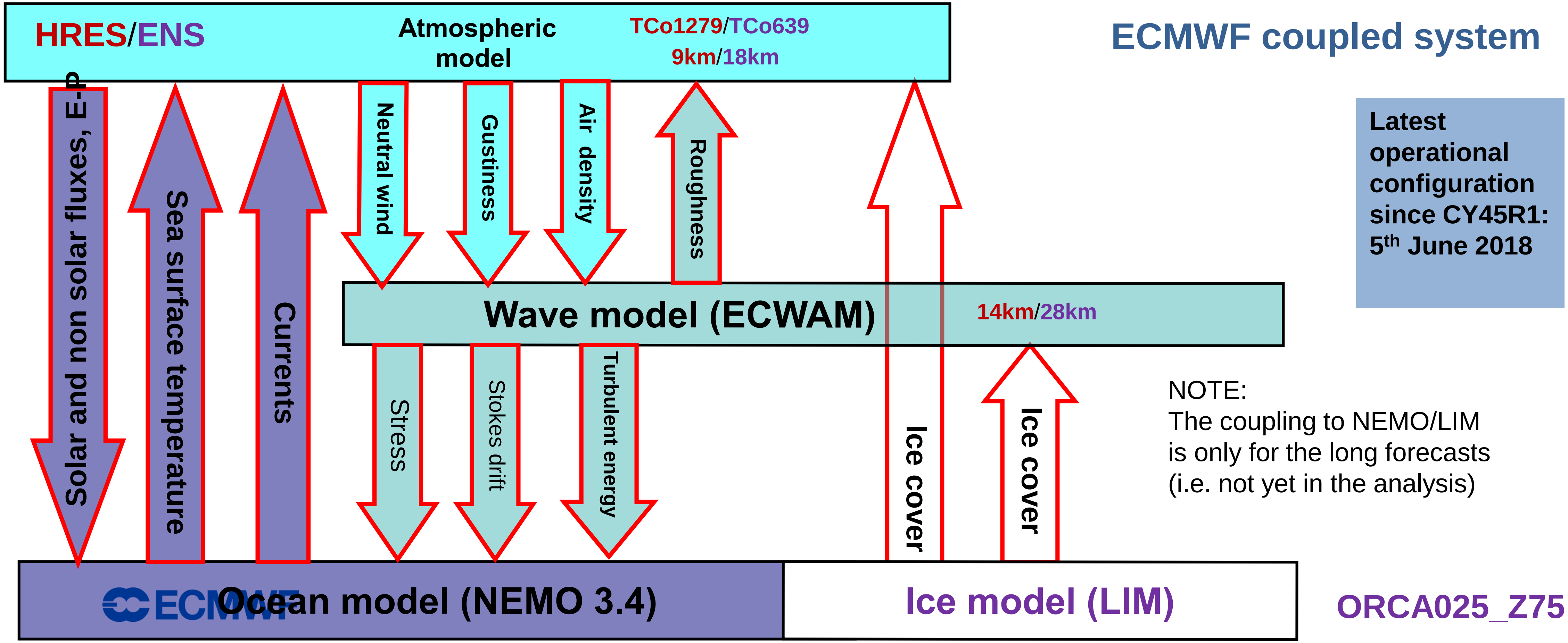


NDBC buoy 41004, Edisto, 76 km Southeast of Charleston, South Carolina, during and after Hurricane Dorian

- **Follow me as I detail what was written in the abstract…**

ECMWF

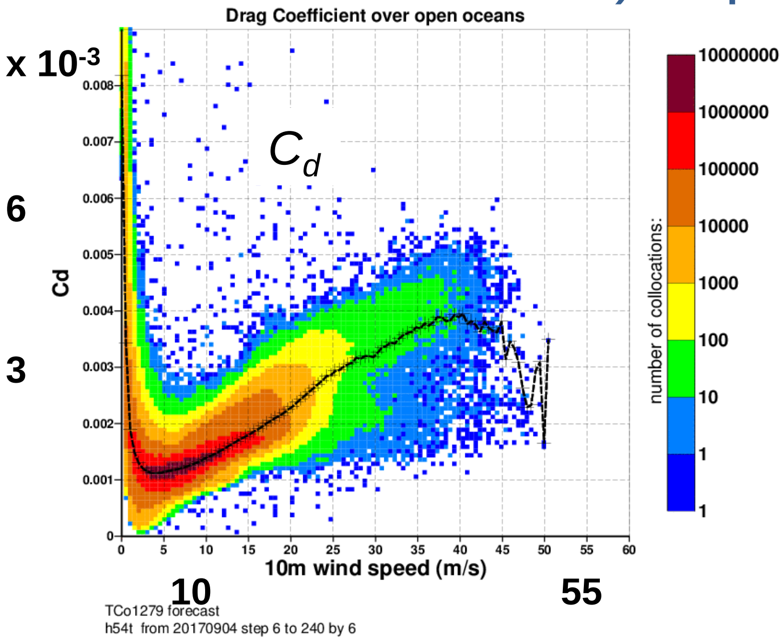
- The global analyses and medium range forecasts from the European Centre for Medium range Weather Forecasts rely on a state-of-the-art Numerical Weather Prediction (NWP) system.
- To best represent the air-sea exchanges, it is tightly coupled to an ocean wave model.
- As part of ECMWF approach to Earth System Model, it is also coupled to a global ocean model for all its forecasting systems from the medium range up to the seasonal time scale.



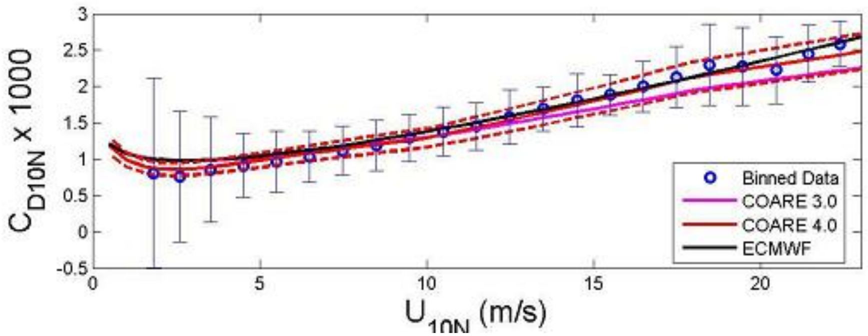
Latest operational configuration since CY45R1: 5th June 2018

NOTE:
The coupling to NEMO/LIM is only for the long forecasts (i.e. not yet in the analysis)

1) Impact of ocean waves on the surface stress



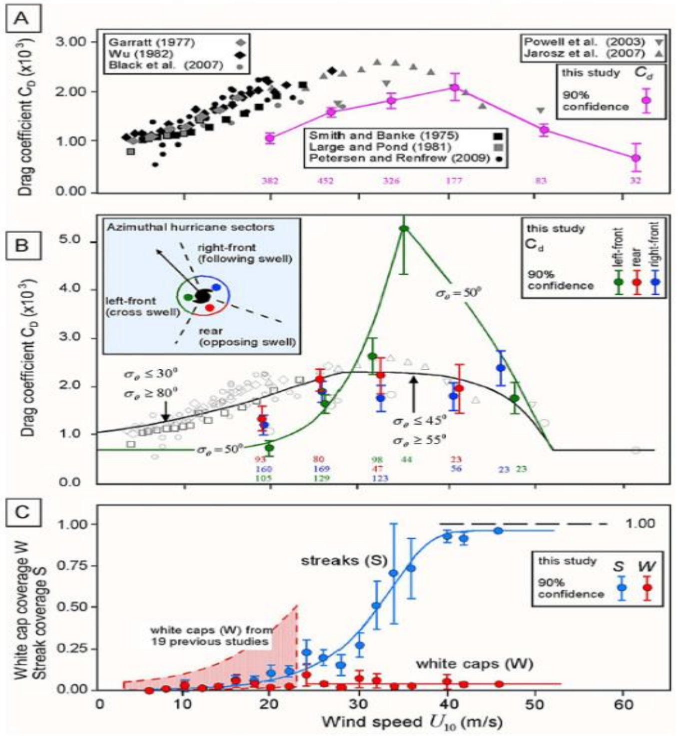
Drag coefficient (C_d)
with respect to wind speed
Operational model (CY46R1)



Edson et al., 2013

C_d fits well observations for winds up to 20m/s
But it might be too high for larger winds

Holthuijsen et al. , 2012



C_d is sea state dependent !

- **Because the feedback from and to the ocean can be significant, it is only in the fully coupled system that parameterisation for air-sea processes should be revisited.**
- **It is now accepted that the drag coefficient should generally attained maximum values for storm winds but should level or even decrease for very strong winds, namely in tropical cyclones or intense mid-latitude wind storms.**

ECMWF

Cd(U10)

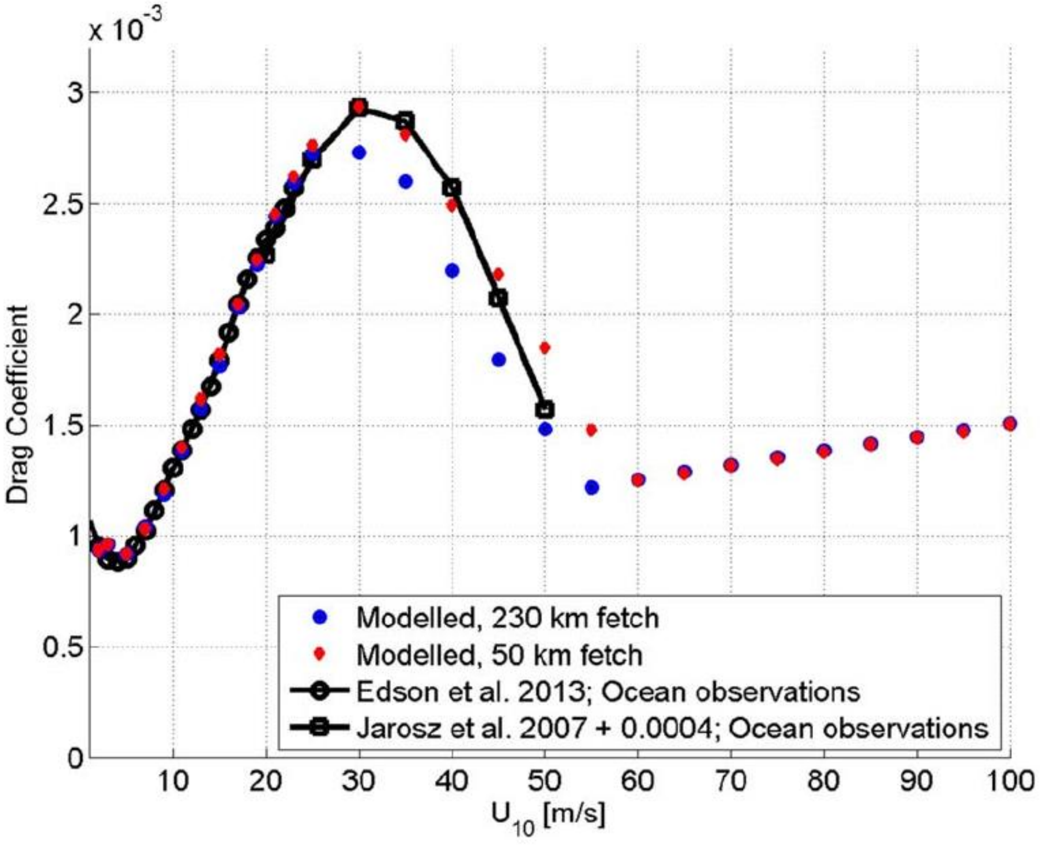
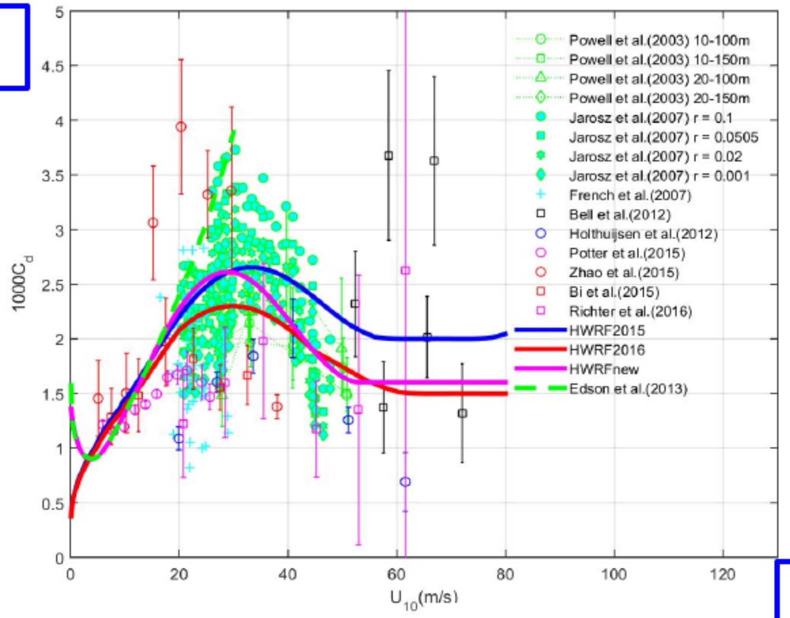


Figure 6. Modeled (with Reynolds number dependent sheltering coefficient, Figure 5, equation (13)) and observed drag coefficients versus wind speed. Note the fetch dependence of the modeled drag coefficient between 30 and 55 m/s.

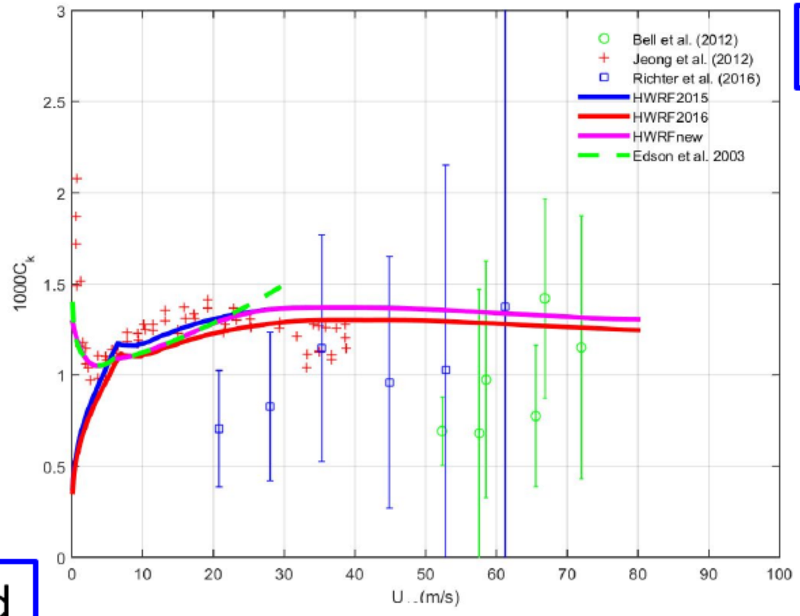
Donelan (2018)

Cd(U10) : HWRF

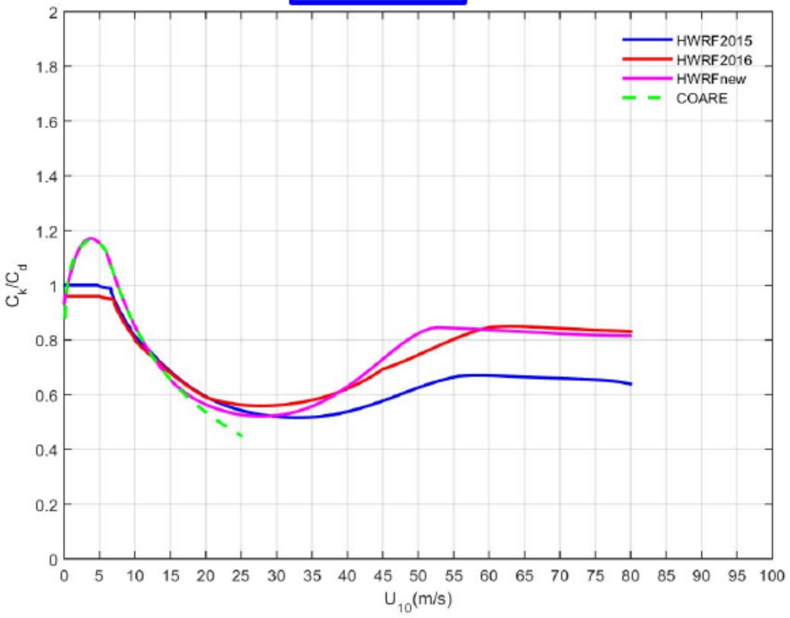
Cd



Ck



Ck/Cd



Magenta: FY2017 HWRF
Red: FY2016 HWRF
Blue: FY2015 HWRF

Low to moderate winds:
Using COARE algorithm
High winds:
Fitting to observed Cd

Emanuel's MPI theory:

$$V_{max}^2 \propto \frac{Ck}{Cd} \times \frac{Ts - To}{Ts} \times (k_0^* - k_a)$$

- **A modification of the wind input source was tested, whereby the Charnock coefficient estimated by the wave model and therefore the drag coefficient sharply reduce for large winds (> 30 m/s).**

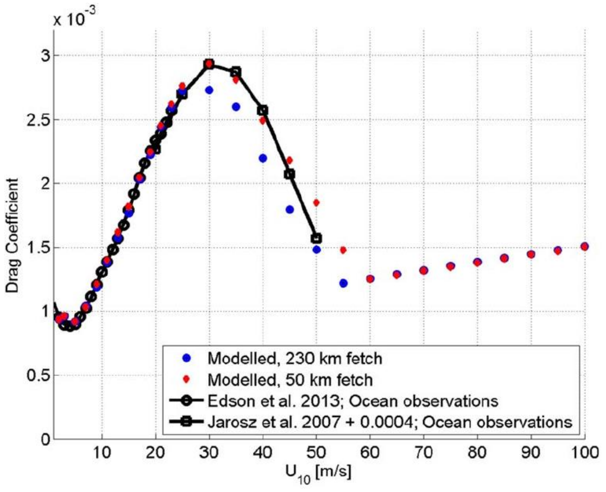


Figure 6. Modeled (with Reynolds number dependent sheltering coefficient, Figure 5, equation (13)) and observed drag coefficients versus wind speed. Note the fetch dependence of the modeled drag coefficient between 30 and 55 m/s.

Donelan (2018)

With the wave model, Charnock is expressed as

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

with

$$\tilde{\alpha} = \tilde{\alpha}_0 = 0.0065$$

In order to mimic Donelan Cd, Charnock has to reduce quite sharply for winds (U_{10}) above 33m/s and then tails off for very high winds:

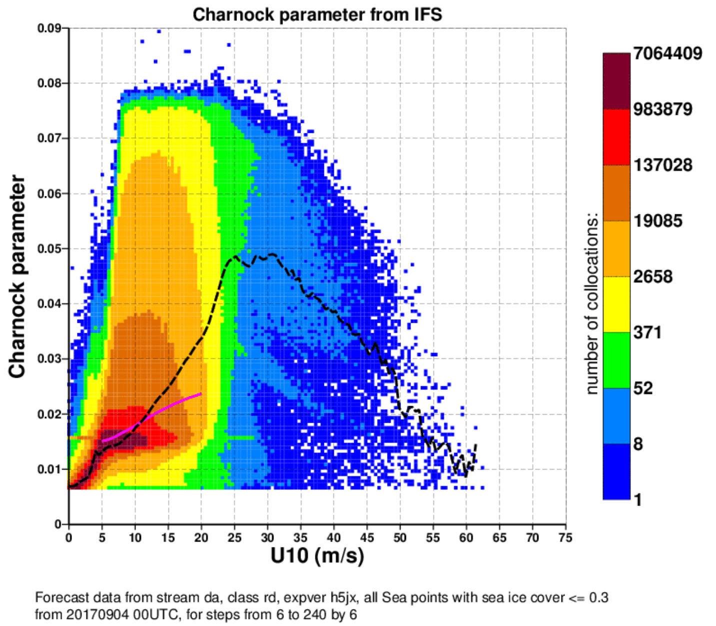
$$\tilde{\alpha} = \tilde{\alpha}_{min} + 0.5(\tilde{\alpha}_0 - \tilde{\alpha}_{min})[1 - \tanh(U_{10} - 33)]$$

with

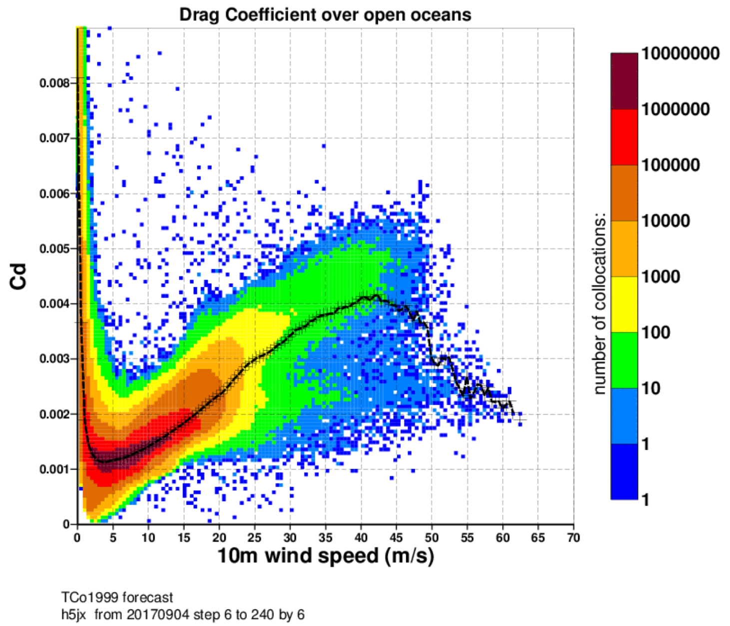
$$\tilde{\alpha}_{min} = 0.0001$$

ECMWF

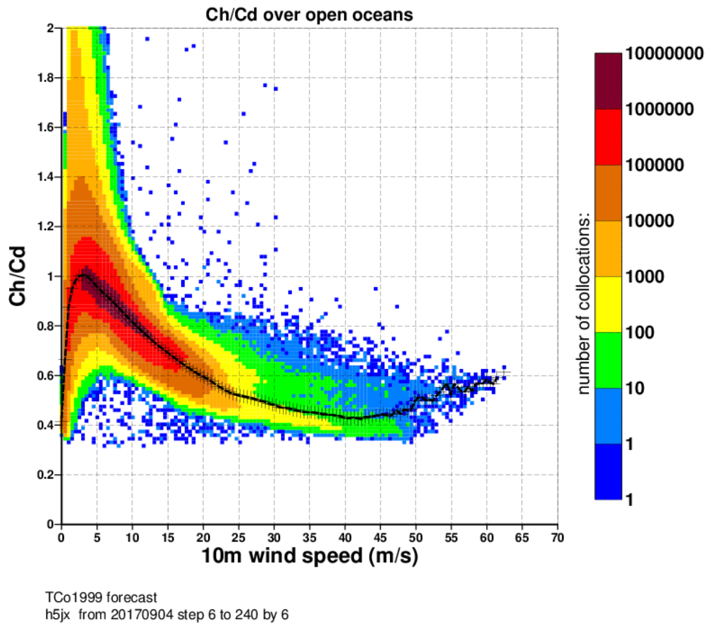
Irma, forecast from 20170904, 0 UTC: with CY46R1 at **Tco1999** (5km)



Charnock v U10



Cd v U10

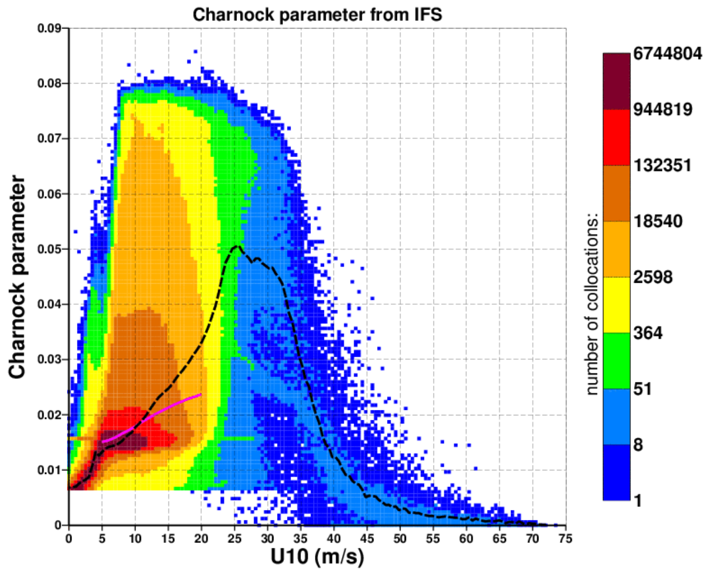


Ch/Cd v U10

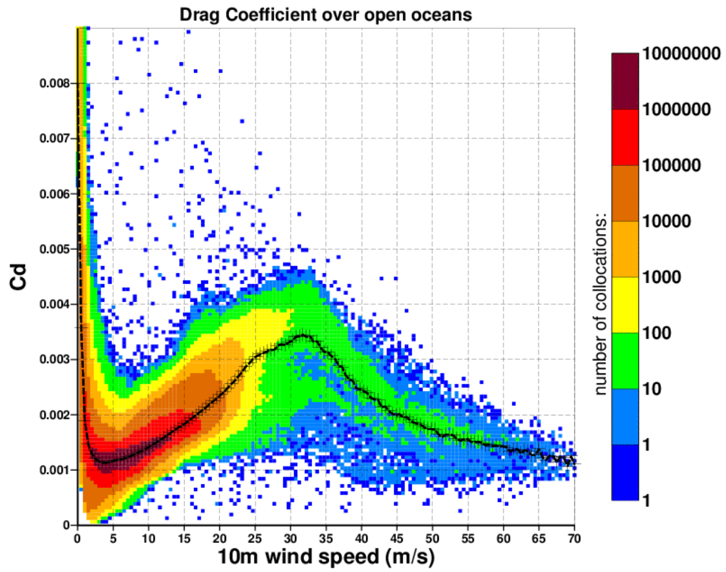
With CY46R1 (2019) wave physics parameterisation

ECMWF

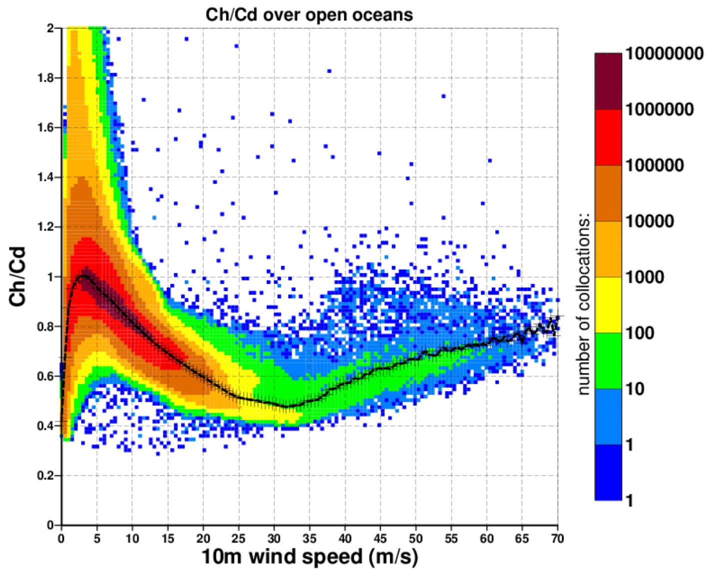
Irma, forecast from 20170904, 0 UTC: CY46R1 **Tco1999** + limitation on Charnock



Forecast data from stream da, class rd, expver h5t7, all Sea points with sea ice cover <= 0.3
from 20170904 00UTC, for steps from 6 to 240 by 6



TCo1999 forecast
h5t7 from 20170904 step 6 to 240 by 6



TCo1999 forecast
h5t7 from 20170904 step 6 to 240 by 6

Charnock v U10

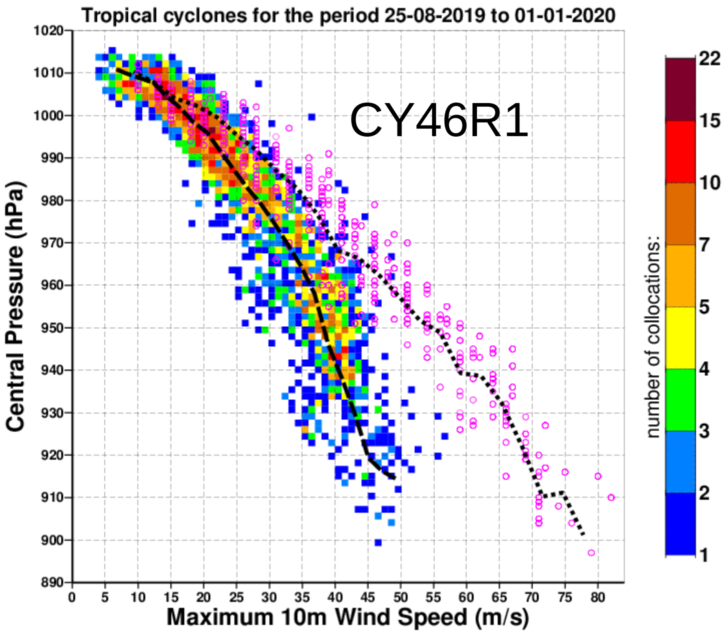
Cd v U10

Ch/Cd v U10

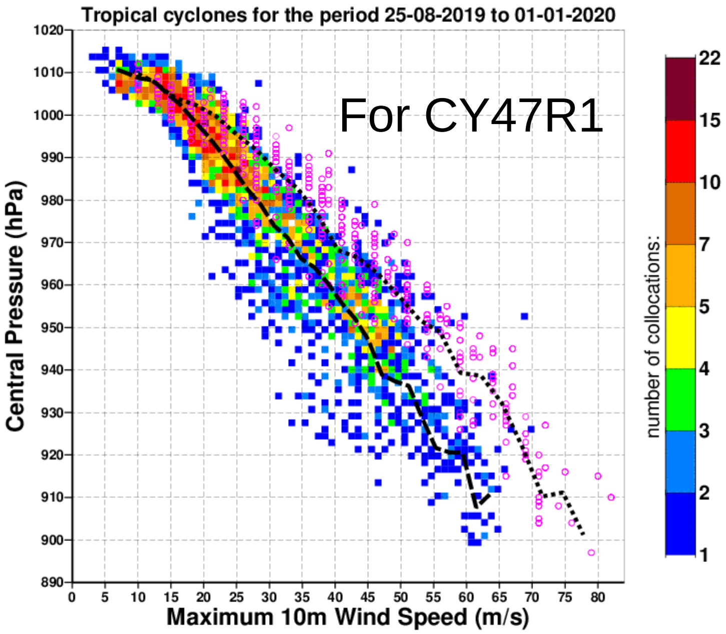
With CY46R1 (2019) wave physics parameterisation

ECMWF

Tropical cyclone max wind - min pressure relationship



Colour shading and dashed line: TCo1279 forecasts (h9s0), all forecasts intialised from 0 UTC.
Pink symbols and dotted line: Best Track data.



Colour shading and dashed line: TCo1279 forecasts (h9s3), all forecasts intialised from 0 UTC.
Pink symbols and dotted line: Best Track data.

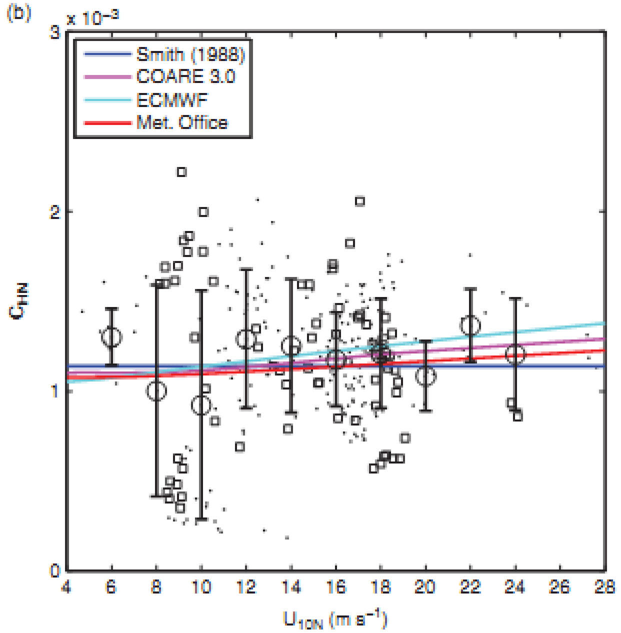
Tco1279 forecasts from 0 UTC for period 25-08-2019 to 01-01-2020 (coloured shading and dotted line). Reported values (pink symbols and dotted line) for tropical cyclones:Ambali, Belna, Bualoi, Calvinia, Dorian, Faxai, Fengshen, Hagibis, Halong, Humberto, Kammuri, Kyarr, Lingling, Lorenzo, Maha, Matmo, Nakri, Phanfone, Sarai, Sebastien.

- **As a consequence, ECMWF tendency to under predict strong tropical cyclones was sharply alleviated, in better agreement with observational evidence.**
- **This change is now planned for operational implementation with the next model cycle (CY47R1, end of June 2020).**

Future developments

2) Impact of ocean waves on heat and moisture fluxes

- **Experimental evidences also point to a sea state/wind dependency of the heat and moisture fluxes.**



Cook and Renfrew 2014

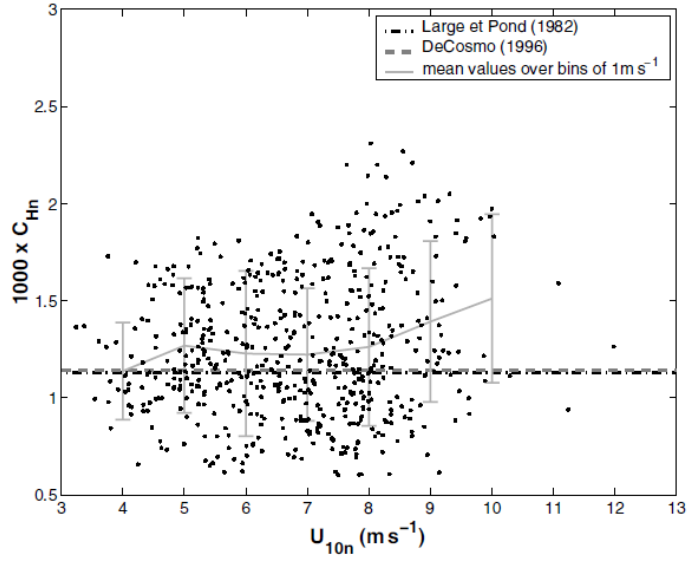
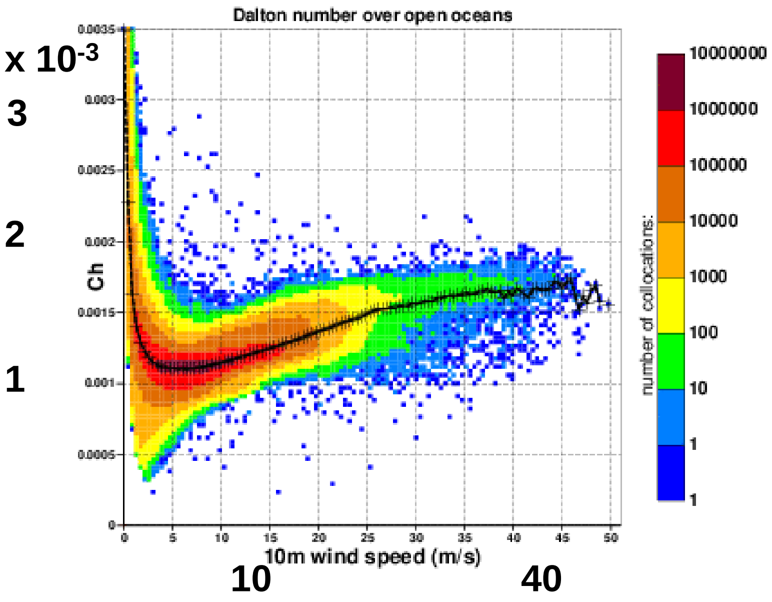


Figure 18. The exchange coefficient for temperature, C_{Hn}, as a function of the neutral wind speed at 10 m, U_{10n}. The dots correspond to 30-minute samples. The solid line with error-bars represents the values averaged over wind speed bins of 1 m s^{-1}. The parametrizations proposed by Large and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

Brut et al. 2005



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

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

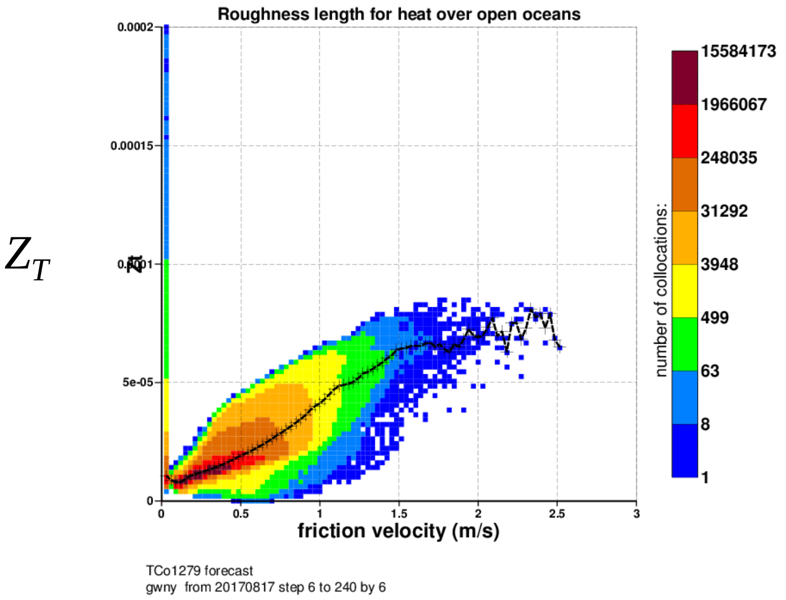
ECMWF

- **Following an extension of the wind wave generation theory, a sea state dependent parameterisation for the roughness length scales for heat and humidity has been tested.**

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

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

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



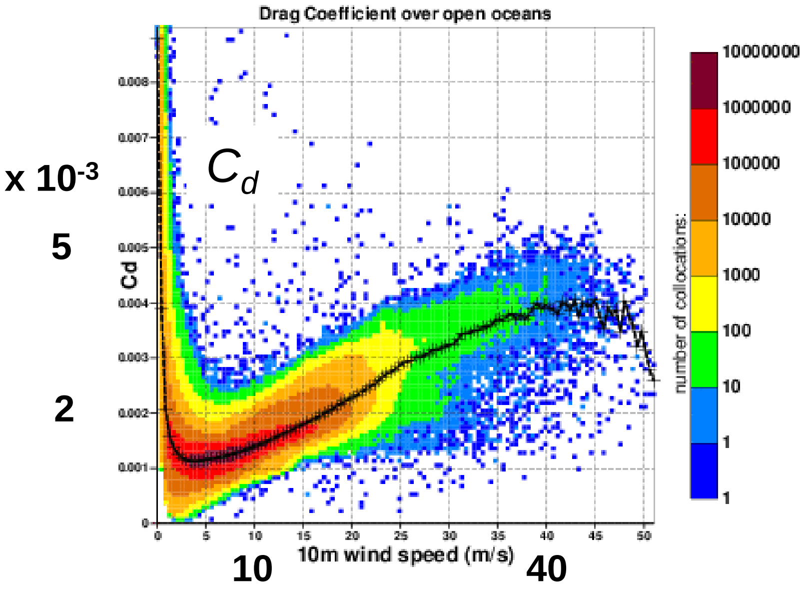
α Sea State dependent Charnock

$\tilde{\alpha}$ minimum Charnock

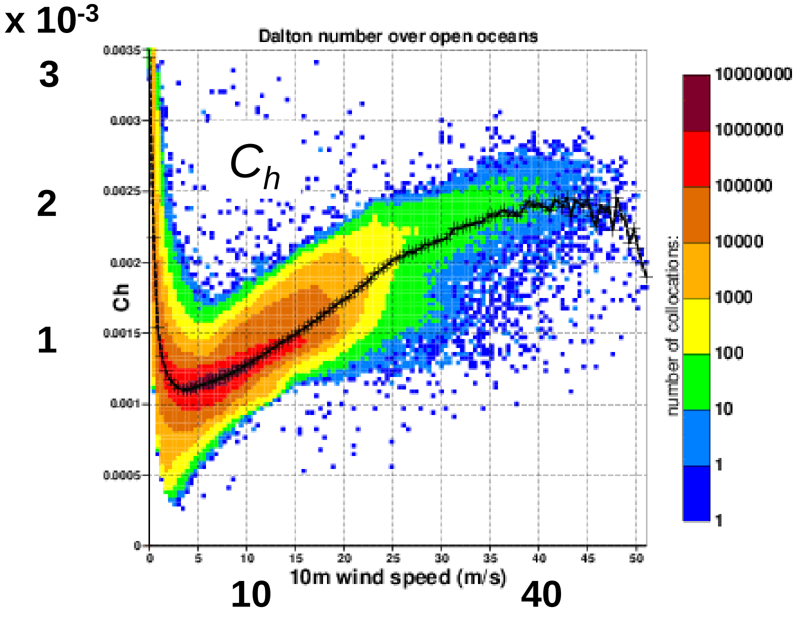
Peter A.E.M.Janssen and Jean-Raymond Bidlot, 2018: Progress in Operational Wave Forecasting, Procedia IUTAM Volume 26, 2018, Pages 14-29.
https://www.sciencedirect.com/science/article/pii/S2210983818300038

ECMWF

Impact of Coupling: revisit parameterisations



Heat exchange coefficients dependency on wind speed



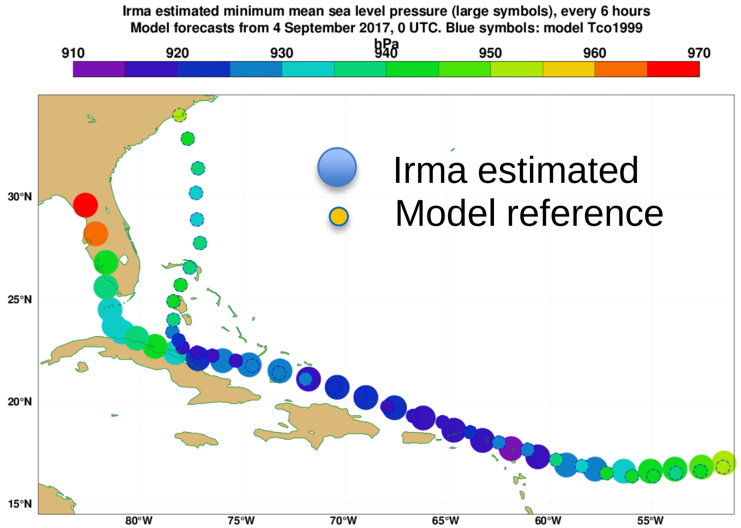
Similarly for moisture flux

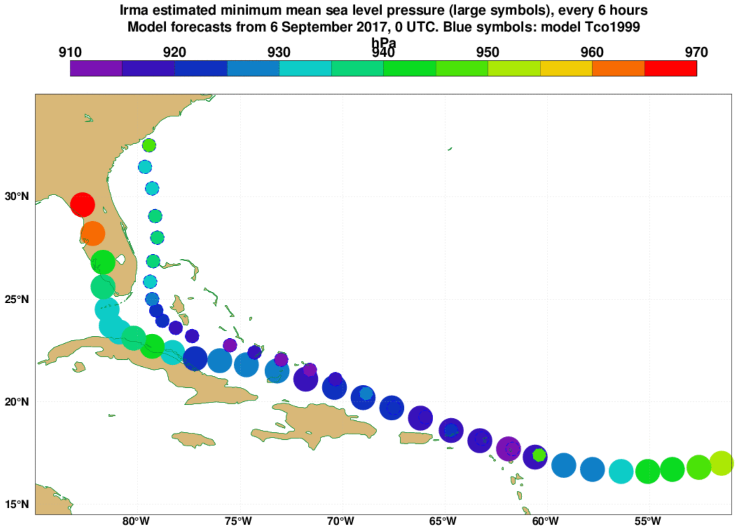
ECMWF

Sensitivity study: Hurricane Irma at Tco1999 resolution (5km)

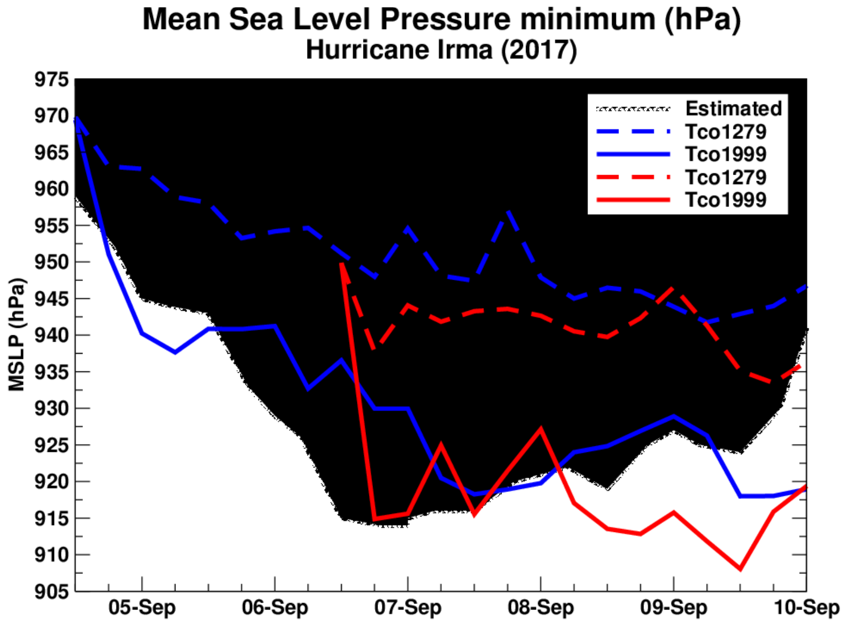
Mean Sea Level Pressure (hPa), every 6 hours.

Forecast from 4 September, 2017, 0 UTC.





Forecast from 6 September, 2017, 0 UTC.



Blue: reference

Red: new parameterisation

NB:
ECMWF, 10 year strategic goal is to run a global ensemble at 5km resolution

Conclusions

- The limitation of Charnock is based on wind speed only.
- Ongoing work with Peter Janssen to extend his theory on wind input to make this limitation dependent on waves parameters by introducing a model for the role of gravity-capillary waves on the overall surface levels.
- Implementing direct wave effect on the exchange coefficients for heat and moisture should be considered in future model cycle.

Thank you for your attention …

Øyvind Breivik, Kristian Mogensen, Jean-Raymond Bidlot, Magdalena Alonso Balmaseda, and Peter A.E.M. Janssen, 2015: Surface Wave Effects in the NEMO Ocean Model: Forced and Coupled Experiments. JGR, doi: 10.1002/2014JC010565

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

Peter A.E.M.Janssen and Jean-Raymond Bidlot, 2018: Progress in Operational Wave Forecasting, Procedia IUTAM Volume 26, 2018, Pages 14-29. https://www.sciencedirect.com/science/article/pii/S2210983818300038

K.S. Mogensen, L. Magnusson and J-R. Bidlot., 2017: Tropical cyclone sensitivity to ocean coupling in the ECMWF coupled model J.Geophys. Res. Oceans, 122, 4392–4412, DOI: 10.1002/2017JC012753

ECMWF