**COARE3.5 in WRF (MYNN scheme)**

* **COARE3.5 wind speed only formulation**

This is already implemented in WRF. However it is not used as the default parametrization (the default is COARE3.0). To set COARE3.5 to default, it is needed to set **COARE\_OPT=3.5** in *phys/module\_sf\_mynn.F.*

**IMPORTANT**: in WRF version prior to WRF 4.4, there was a mistake in the coefficients used in the “*edson\_etal\_2013”* subroutine to calculate the Charnock coefficient. m=0.017 is wrong and should be **m=0.0017** (cf. Edson et al. 2014: corrigendum to Edson et al. 2013)

* **COARE3.5 wave-based formulations**

Hereafter the modifications concern the implementation of the alternative formulations of COARE3.5 using explicit wave fields (as described in Edson et al. 2013). To do so, new variables need to be created in the *wrflowinp* file to be read by WRF.

The new variable names are HS\_WAVE , TP\_WAVE for significant wave height and peak period, respectively

1. **Step by Step modifications**

* InRegistry/Registry.EM\_COMMON

add 2 lines:

**state real HS\_WAVE ij misc 1 - i0124rd=(interp\_mask\_water\_field:lu\_index,iswater) "HS\_WAVE" "SIGNIFICANT WAVE HEIGHT" "m"**

**state real TP\_WAVE ij misc 1 - i0124rd=(interp\_mask\_water\_field:lu\_index,iswater) "TP\_WAVE" "WAVE PEAK PERIOD" "s"**

* In Registry/Registry.NMM

add 2 lines:

**state real HS\_WAVE ij misc 1 - i014rh023 "HS\_WAVE" "SIGNIFICANT WAVE HEIGHT" "m"**

**state real TP\_WAVE ij misc 1 - i014rh023 "TP\_WAVE" "WAVE PEAK PERIOD" "s"**

* In dyn\_em/module\_first\_rk\_step\_part1.F

in the CALL surface\_driver add the variables:

**HS\_WAVE=grid%hs\_wave ,TP\_WAVE=grid%tp\_wave**

in the subroutine TURBL add :

**HS\_WAVE,TP\_WAVE**

and declare the variables:

**REAL,DIMENSION(IMS:IME,JMS:JME),INTENT(OUT) :: HS\_WAVE,TP\_WAVE**

In the CALL SURFACE\_DRIVER add:

**HS\_WAVE=HS\_WAVE,TP\_WAVE=TP\_WAVE**

In the CALL PBL\_DRIVER add:

(I think this one may be skipped but still doing it to be sure)

**HS\_WAVE=HS\_WAVE,TP\_WAVE=TP\_WAVE**

* In phys/module\_surface\_driver.F

in SUBROUTINE surface\_driver add here :

! Other options (more or less em specific)

**hs\_wave,tp\_wave**

Then declare the variables :

**REAL, DIMENSION( ims:ime, jms:jme ), INTENT(INOUT),OPTIONAL :: HS\_WAVE**

**REAL, DIMENSION( ims:ime, jms:jme ), INTENT(INOUT),OPTIONAL :: TP\_WAVE**

in CALL MYNN\_SEAICE\_WRAPPER and CALL SFCLAY\_mynn add:

**hs\_wave,tp\_wave,**

in SUBROUTINE mynn\_seaice\_wrapper add:

**HS\_WAVE,TP\_WAVE**

and declare :

**REAL, DIMENSION( ims:ime, kms:kme, jms:jme ) , &**

**INTENT(IN ) :: HS\_WAVE, TP\_WAVE**

in this subroutine there are two CALL SFCLAY\_mynn add:

**HS\_WAVE,TP\_WAVE,**

* In phys/module\_sf\_mynn.F

in SUBROUTINE SFCLAY\_mynn add:

**HS\_WAVE,TP\_WAVE,**

and declare:

**REAL, DIMENSION( ims:ime, jms:jme ) , &**

**INTENT(IN ) :: HS\_WAVE,TP\_WAVE**

in CALL SFCLAY1D\_mynn add:

**HS\_WAVE(ims,j),TP\_WAVE(ims,j)**

In SUBROUTINE SFCLAY1D\_mynn add:

**HS\_WAVE,TP\_WAVE**

and declare:

**REAL, DIMENSION( ims:ime ), INTENT(IN) :: HS\_WAVE,TP\_WAVE**

1. **COARE3.5 subroutine related modifications**

In **phys/module\_sf\_mynn.F**

If not already, change COARE\_OPT to use COARE 3.5 as default :

COARE\_OPT=3.5

In SUBROUTINE SFCLAY1D\_mynn

I created new options for the namelist parameter **ISFTCFLX** calling a new subroutine to calculate the surface roughness (z0) with waves, add:

**ELSEIF ( ISFTCFLX .EQ. 351 ) THEN**

**CALL edson\_etal\_2013\_wave1(ZNT(i),UST(i),WSPD(i),visc,ZA(I),TP\_WAVE(I))**

**ELSEIF ( ISFTCFLX .EQ. 352 ) THEN**

**CALL edson\_etal\_2013\_wave2(ZNT(i),UST(i),WSPD(i),visc,ZA(I),HS\_WAVE(I),TP\_WAVE(I))**

-to calculate zq and zt use the same routine as COARE3.5:

**ELSEIF ( ISFTCFLX .EQ. 351 ) THEN**

**CALL fairall\_etal\_2014(z\_t(i),z\_q(i),restar,UST(i),visc,rstoch1D(i),spp\_pbl)**

**ELSEIF ( ISFTCFLX .EQ. 352 ) THEN**

**CALL fairall\_etal\_2014(z\_t(i),z\_q(i),restar,UST(i),visc,rstoch1D(i),spp\_pbl)**

then add the new subroutine, almost same as the original on:

SUBROUTINE edson\_etal\_2013\_wave1(Z\_0,ustar,visc,**tp**)

!Implementation of the COARE3.5 formulation using wage-age

! form [Edson et al. 2013]

! Charnock coefficient is now dependant of wave age

!Cesar Sauvage 04/2021

IMPLICIT NONE

REAL, INTENT(IN) :: ustar, visc

**REAL, INTENT(IN) :: tp ! wave period**

REAL, INTENT(OUT) :: Z\_0

REAL, PARAMETER :: G=9.81

**REAL, PARAMETER :: PI=3.1415927, A=0.114,B=0.622 !!**

REAL :: CZC ! variable charnock

**REAL :: cp ! phase speed of wave**

**!wave phase speed**

**cp=G\*tp/(2\*PI)**

!Charnock coefficient

**CZC=A\*(ustar/cp)\*\*B;**

!surface roughness length

Z\_0 = CZC\*ustar\*ustar/G + (0.11\*visc/MAX(ustar,0.07))

Z\_0 = MAX( Z\_0, 1.27e-7) !These max/mins were suggested by

!Z\_0 = MIN( Z\_0, 2.85e-3) !Davis et al. (2008)

return

END SUBROUTINE edson\_etal\_2013\_wave1

!--------------------------------------------------------------------

SUBROUTINE edson\_etal\_2013\_wave2(Z\_0,ustar,wsp10,visc,zu**,hs,tp**)

!Implementation of the COARE3.5 formulation using wage-age and significant wave height

! form [Edson et al. 2013]

! Charnock coefficient is now dependant of wave age and wave height

!Cesar Sauvage 04/2021

IMPLICIT NONE

REAL, INTENT(IN) :: ustar, visc, wsp10, zu, **hs, tp**

REAL, INTENT(OUT) :: Z\_0

**REAL, PARAMETER :: G=9.81**

**REAL, PARAMETER :: PI=3.1415927, Ad=0.2,Bd=2.2 !! CS**

REAL, PARAMETER :: m=0.0017, b=-0.005

REAL :: CZC ! variable charnock "constant"

REAL :: wsp10m ! logarithmically calculated 10 m

**REAL :: cp,zoS ! !CS**

**!wave phase speed CS**

**cp=G\*tp/(2\*PI)**

wsp10m = wsp10\*log(10/1e-4)/log(zu/1e-4)

wsp10m = MIN(19., wsp10m)

**zoS=hs\*Ad\*(ustar/cp)\*\*Bd**

**CZC=zoS\*G/ustar/ustar**

Z\_0 = CZC\*ustar\*ustar/G + (0.11\*visc/MAX(ustar,0.07))

Z\_0 = MAX( Z\_0, 1.27e-7) !These max/mins were suggested by

!Z\_0 = MIN( Z\_0, 2.85e-3) !Davis et al. (2008)

return

END SUBROUTINE edson\_etal\_2013\_wave2

!--------------------------------------------------------------------

1. **New wave-based formulations**

Based on Edson et al. 2013 and following Sauvage et al (under review), 2 new wave-based formulations are added.

**3.1 Including alignment wind-waves**

This approach is inspired by the work of Porchetta et al. 2019 including the angle between wind and waves in the surface roughness calculation. A new variable, THETA\_WW, needs to be created in the *wrflowinp and will be read by WRF. Follow the previous steps in Section 2 to add a new variable.*

*Then in* ***phys/module\_sf\_mynn.F***

**ELSEIF ( ISFTCFLX .EQ. 353 ) THEN**

**CALL edson\_etal\_2013\_wave3(ZNT(i),UST(i),visc,HS\_WAVE(I),TP\_WAVE(I),THETA\_WW(I))**

**ELSEIF ( ISFTCFLX .EQ. 353 ) THEN**

**CALL fairall\_etal\_2014(z\_t(i),z\_q(i),restar,UST(i),visc,rstoch1D(i),spp\_pbl)**

then add the new subroutine:

SUBROUTINE edson\_etal\_2013\_wave3(Z\_0,ustar,visc,hs,tp,theta)

!Implementation of the COARE3.5 formulation using wage-age and sea state

! form [Edson et al. 2013]

! z0 = z0\_rough + z0\_smooth

! z0\_rough is now dependant of wave age and significant wave height

! whereas z0\_smooth stay the same and is a viscosity term

! now includinf the angle difference between wind and wave

!Cesar Sauvage 08/2021

IMPLICIT NONE

REAL, INTENT(IN) :: ustar, visc

REAL, INTENT(IN) :: hs, tp ! significant wave height and wave period

**REAL, INTENT(IN) :: theta ! angle diff between wind and wave (0 - 180)**

REAL, INTENT(OUT) :: Z\_0

REAL, PARAMETER :: G=9.81

REAL, PARAMETER :: PI=3.1415927, Ad=0.091,Bd=2.0 !!

REAL :: cp ! phase speed of wave

**REAL :: Ad\_new, Bd\_new ! coef**

!wave phase speed

cp=G\*tp/(2\*PI)

!new coef

**Ad\_new=Ad\*COS(0.45\*theta)**

**Bd\_new=Bd\*COS(-0.32\*theta)**

!surface roughness length

**Z\_0=hs\*Ad\_new\*(ustar/cp)\*\*Bd\_new + (0.11\*visc/MAX(ustar,0.07))**

Z\_0 = MAX( Z\_0, 1.27e-7) !These max/mins were suggested by

!Z\_0 = MIN( Z\_0, 2.85e-3) !Davis et al. (2008)

return

END SUBROUTINE edson\_etal\_2013\_wave3

!--------------------------------------------------------------------

**3.2 Using the mean period of the waves instead of the peak period**

This method does not need the creation of a new variable but instead of providing the peak period in the *wrflowinp* we are now providing the mean period of the wave. Thus, the coefficients in COARE3.5 are adjusted to the use of the mean period.

*In* ***phys/module\_sf\_mynn.F***

**ELSEIF ( ISFTCFLX .EQ. 354 ) THEN**

**CALL edson\_etal\_2013\_wave4(ZNT(i),UST(i),visc,HS\_WAVE(I),TP\_WAVE(I))**

**ELSEIF ( ISFTCFLX .EQ. 354 ) THEN**

**CALL fairall\_etal\_2014(z\_t(i),z\_q(i),restar,UST(i),visc,rstoch1D(i),spp\_pbl)**

then add the new subroutine:

SUBROUTINE edson\_etal\_2013\_wave4(Z\_0,ustar,visc,hs,tp)

!Implementation of the COARE3.5 formulation using wage-age and sea state

! form [Edson et al. 2013]

! z0 = z0\_rough + z0\_smooth

! z0\_rough is now dependant of wave age and significant wave height

! whereas z0\_smooth stay the same and is a viscosity term

! using the mean period instead of peak period

!Cesar Sauvage 09/2021

IMPLICIT NONE

REAL, INTENT(IN) :: ustar, visc

REAL, INTENT(IN) :: hs, tp ! significant wave height and wave period

REAL, INTENT(OUT) :: Z\_0

REAL, PARAMETER :: G=9.81

**REAL, PARAMETER :: PI=3.1415927, Ad\_t0=0.39,Bd\_t0=2.6 !!**

REAL :: cp ! phase speed of wave

!wave phase speed

cp=G\*tp/(2\*PI)

!surface roughness length

**Z\_0=hs\*Ad\_t0\*(ustar/cp)\*\*Bd\_t0 + (0.11\*visc/MAX(ustar,0.07))**

Z\_0 = MAX( Z\_0, 1.27e-7) !These max/mins were suggested by

!Z\_0 = MIN( Z\_0, 2.85e-3) !Davis et al. (2008)

return

END SUBROUTINE edson\_etal\_2013\_wave4

!--------------------------------------------------------------------

1. **Compile and Run WRF**

**------------------------------------------------------------------**

**Compile WRF again**

**./clean -a**

**./configure**

**./compile em\_real > log**

**---------------------------------------------------------------------**

**Running WRF** :

Running the **./real.x** should now create HS\_WAVE, TP\_WAVE and THETA\_WW in the *wrflowinp* which can then be filled by desired wave fields (i.e. ERA5 wave fields).

in the namelist.input, under Physics :

isftcflx = 0 !! to use the default COARE3.5 wind speed only parametrization

**OR**

isftcflx = 351 !! to use the modified COARE3.5 with wave age only.

**OR**

isftcflx = 352 !! to use the modified COARE3.5 with wave age+ wave height together.

**OR**

isftcflx = 353 !! to use the modified COARE3.5 with wave age + wave height + angle wind-waves.

**OR**

isftcflx = 354 !! to use the modified COARE3.5 with wave age+ wave height; wave age is now calculated using the mean period of the waves.