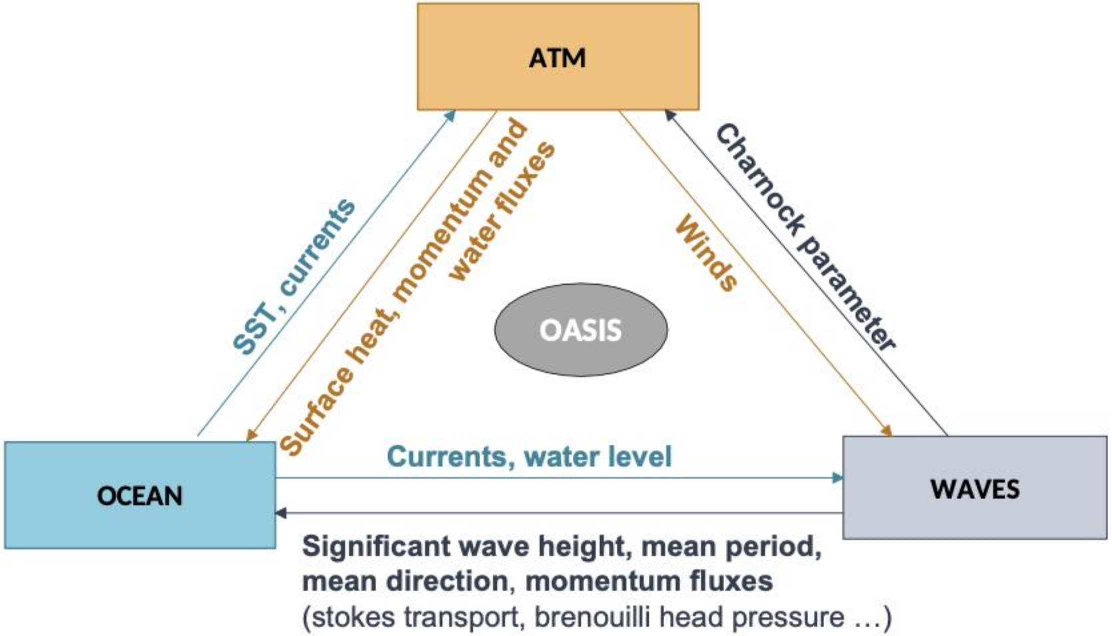
# Coupling CROCO with other models using OASIS

# Coupling philosophy



# Coupling philosophy

**OASIS-MCT** (Ocean-Atmosphere-Sea-Ice-Soil, Model Coupling Toolkit) is a coupler developed at CERFACS, Toulouse, France.

OASIS

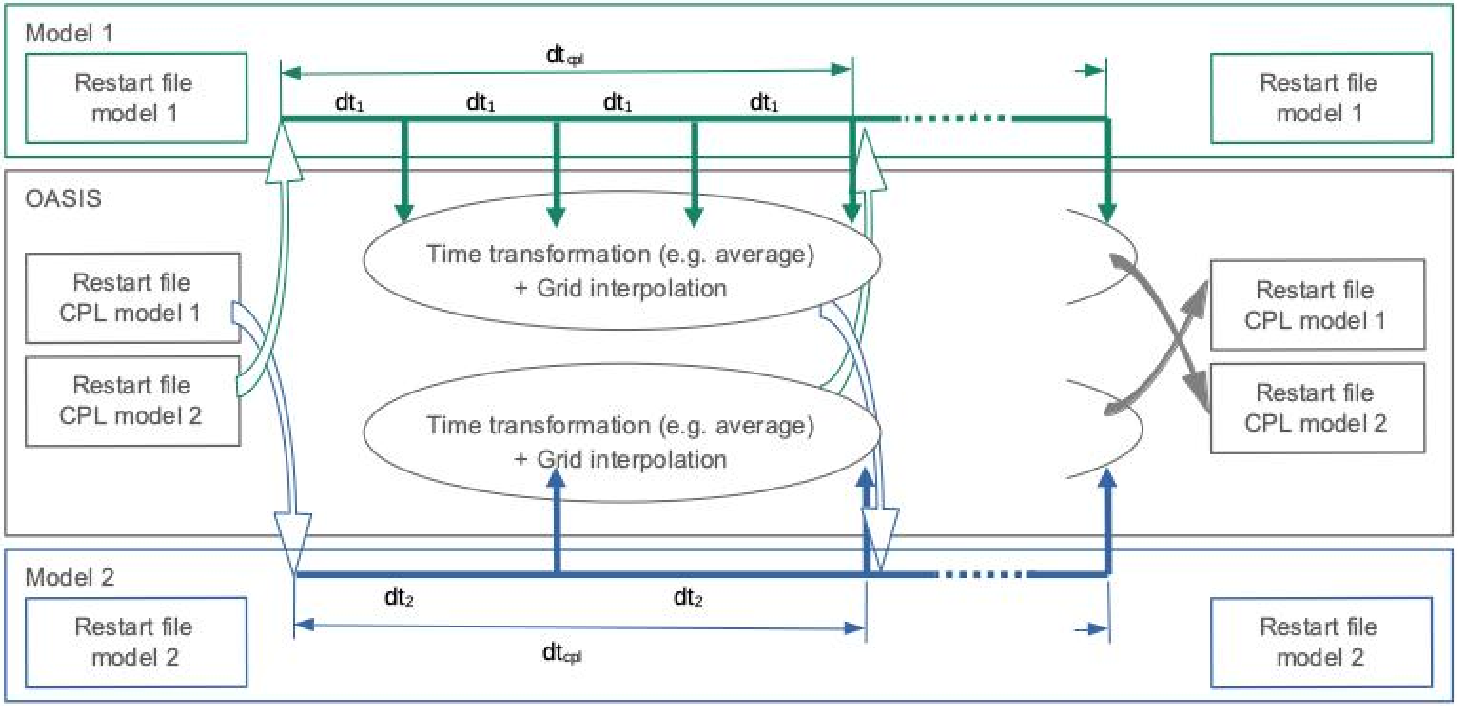
It is a **set of libraries** (not an executable file) providing functions which are called in the models themselves:

- Exchange of variables and time interpolations (PSMILE library)
- Parallel exchanges (MCT library)
- Grid interpolations (SCRIPR library)

It has the **advantage** of being:

- non-intrusive, easy implementation: only a few calls in the model time stepping, and a few additional routines
- A common interface for a variety of models (e.g. CROCO, NEMO, SURFEX, WW3…)

# Coupling sequence



# Transformations performed by OASIS

The OASIS3-MCT coupler can process:

- time transformations (**LOCTRANS**):
  - INSTANT no time transformation, the instantaneous field is transferred
  - ACCUMUL the accumulated field over the coupling period is exchanged
  - AVERAGE the averaged field over the coupling period is transferred
  - T_MIN the minimum value of the field for each source grid point over the coupling period is transferred
  - T_MAX the maximum value of the field for each source grid point over the coupling period is transferred

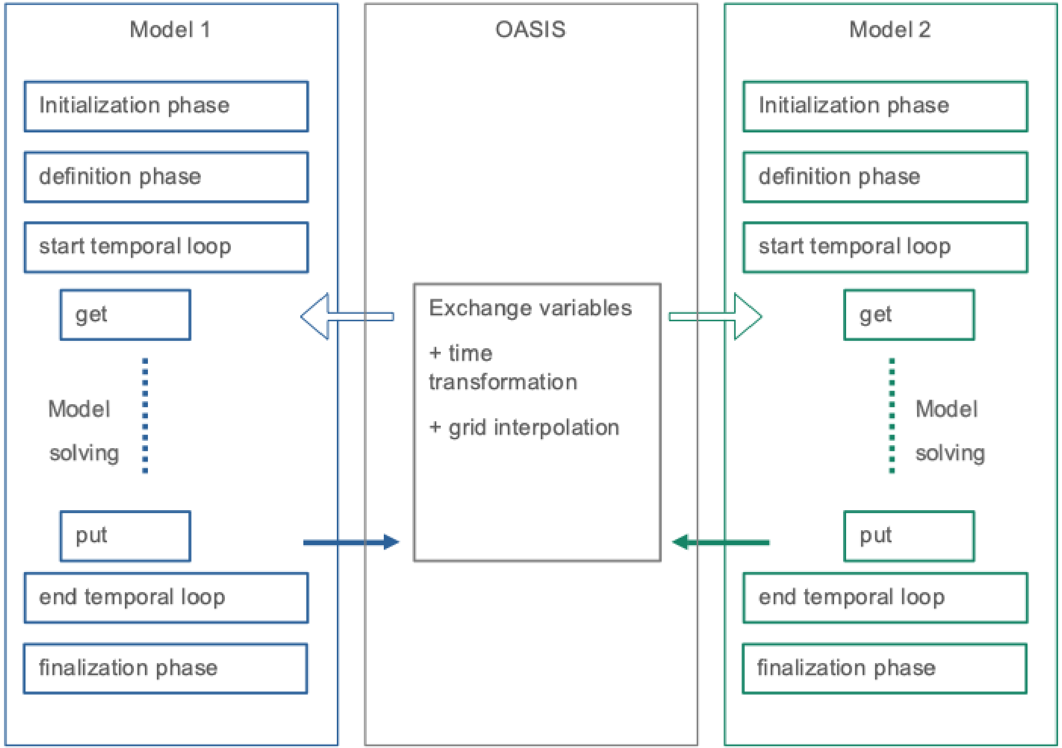
- 2D spatial interpolations (**SCRIPR**):
  - BILINEAR interpolation based on a local bilinear approximation
  - BICUBIC interpolation based on a local bicubic approximation
  - CONSERV 1st or 2nd order conservative remapping
  - DISTWGT distance weighted nearest-neighbour interpolation (N neighbours)
  - GAUSWGT N nearest-neighbour interpolation weighted by their distance and a Gaussian function

See OASIS manual for more detailed information

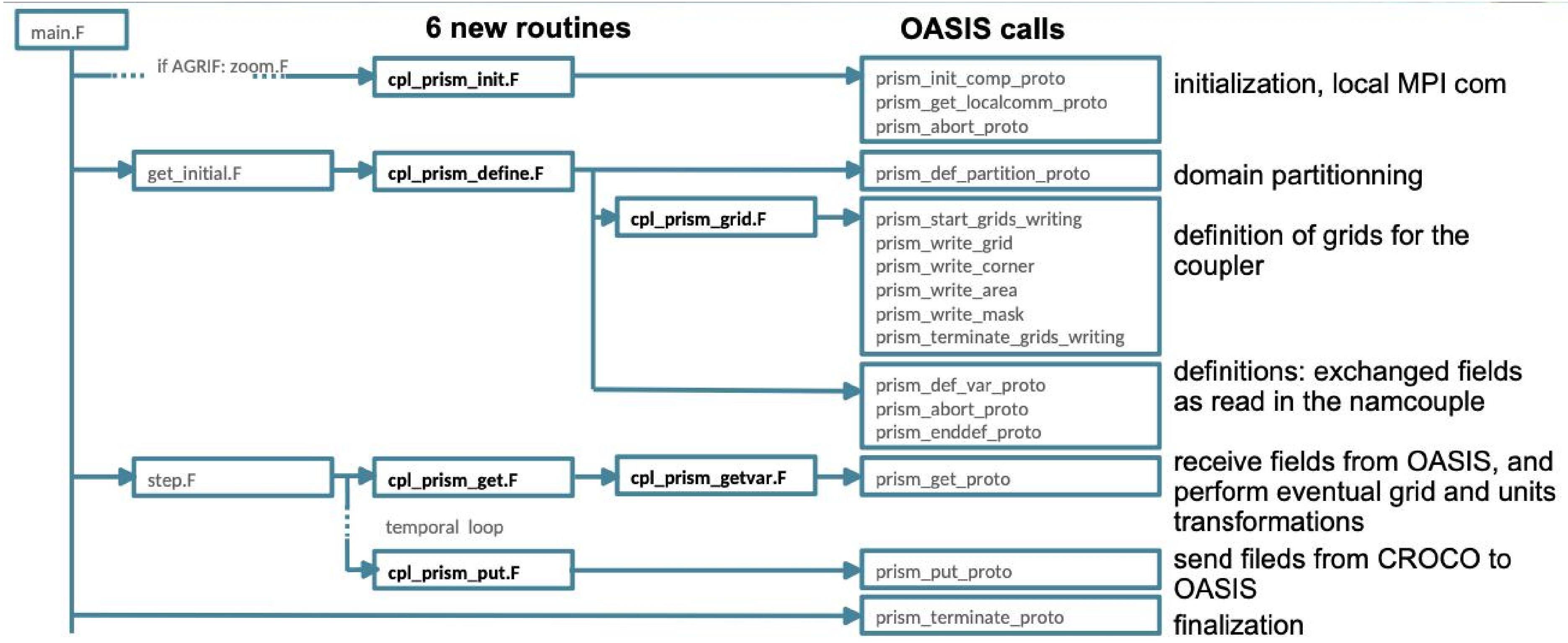
# Implementation in general

OASIS-MCT implementation calls:

- **Initialization**
  oasis_init_comp(…)
  oasis_get_localcomm(..)
- **Definitions**
  oasis_write_grid(…)
  oasis_def_partitions(…)
  oasis_def_var(…)
- **Exchange fields** (witin time stepping)
  oasis_put(…)
  oasis_get(…)
- **Finalization**
  oasis_terminate(…)



# Detailed implementation in CROCO



# Roadmap for the working group

**Objectifs :**
- Représenter les processus de couplage OVA
- avec une hiérarchie de modèles plus ou moins complexes
- et relativement "facile/accessible" à mettre en œuvre

**Enjeux :**

Interactions OVA / toutes les boucles de rétroactions → Variables échangées, consistance
Robustesse, efficacité → OASIS
Paramétrisations du couplage (simplification cpl) → CFB, bulk ré-écrite, ABL1D
Echelles spatiales, multigrilles des différents modèles → Gestion du nesting en couplé
Inter-comparaison forcé/couplé (framework adapté) → Fichiers de forçage
Rendre accessible le couplage → Tools

**Verrous :**

Inconsistances des bulks
Prise en compte des vagues via Charnock, peu d'alternatives...
Paramétrisations pour les extrêmes : pertinence ?
Vers le littoral / wet-dry...

# Ocean – Atmosphere coupling

**O → A**

- SST
- Currents (on the grid or north/east)

**A → O**

- Water flux (E-P)
- Solar flux
- Total heat flux
- Momentum flux (on the grid or north/east)
- Mean sea level Pressure (→ pb with OBC_PATM to solve)

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Simplifications et parametrisations :

→ ABL 1D (cf présentation Joris)
→ CFB

# CFB parameterization

Momentum flux: $\tau = \tau_a + s_\tau . U_o$ ***with*** $s_\tau = -0.0029.|U_a| + 0.008$

Heat fluxes (use of relative wind): $U_r = U_a - (1-s_w).U_o$ ***with*** $s_w \approx 0.3$

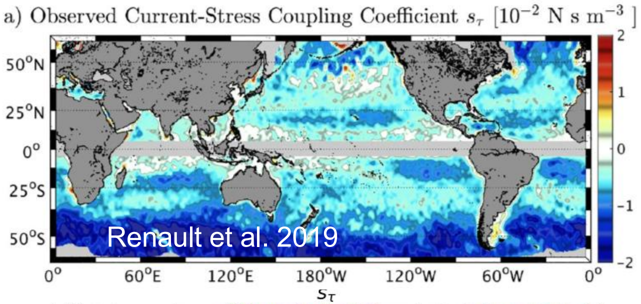
in cppdefs.h : **SFLUX_CFB**
**CFB_STRESS**
**CFB_WIND_TRA**

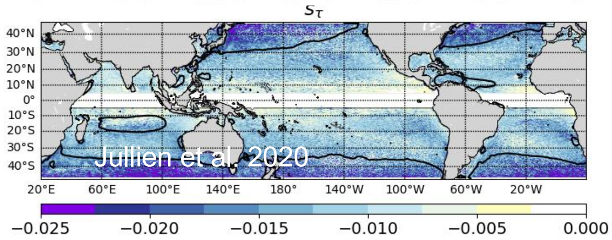
in params_bulk.h:

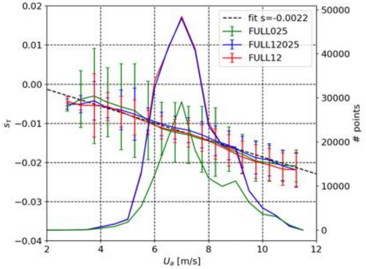
```
real cfb_slope, cfb_offset
parameter (cfb_slope=-0.0029)
parameter (cfb_offset=0.008)

real swparam
parameter (swparam=0.3)
```

Then used in bulk_flux.F and get_bulk.F.

=> N. Ernout : starting PhD on CFB parameterization with machine learning



# Wave-current coupling

## Wave averaged-current coupled equations (vortex force formalism)

$$\xi^c = \xi + \hat{\xi}$$

$\xi^c$ is a composite sea level,

$$\phi^c = \phi + \hat{\phi}$$

$\phi^c$ absorbs the Bernoulli head $\hat{\phi}$,

$$\vec{\mathbf{v}}_L = \vec{\mathbf{v}} + \vec{\mathbf{v}}_S$$

$\vec{\mathbf{v}}_L$ is the wave-averaged Lagrangian velocity, Stokes drift $\vec{\mathbf{v}}_S$

$\mathcal{F^W}_u, \mathcal{F^W}_v, \mathcal{F^W}_C$ : wave forcing terms (bottom streaming, breaking acceleration)

$\mathcal{D}_u, \mathcal{D}_v, \mathcal{D}_C$ : diffusive terms (including wave-enhaced bottom drag and mixing)

$\mathcal{F}_u, \mathcal{F}_v, \mathcal{F}_C$ : forcing terms

$$\frac{\partial u}{\partial t} + \vec{\nabla}.\left(\vec{\mathbf{v}}_L u\right) - f v_L = -\frac{\partial \phi^c}{\partial x} + \left(u_S \frac{\partial u}{\partial x} + v_S \frac{\partial v}{\partial x}\right) + \mathcal{F}_u + \mathcal{D}_u + \mathcal{F^W}_u$$

$$\frac{\partial v}{\partial t} + \vec{\nabla}.\left(\vec{\mathbf{v}}_L v\right) + f u_L = -\frac{\partial \phi^c}{\partial y} + \left(u_S \frac{\partial u}{\partial y} + v_S \frac{\partial v}{\partial y}\right) + \mathcal{F}_v + \mathcal{D}_v + \mathcal{F^W}_v$$

$$\frac{\partial \phi^c}{\partial z} + \frac{\rho g}{\rho_0} = \vec{\mathbf{v}}_S . \frac{\partial \vec{\mathbf{v}}}{\partial z}$$

$$\frac{\partial C}{\partial t} + \vec{\nabla}.\left(\vec{\mathbf{v}}_L C\right) = \mathcal{F}_C + \mathcal{D}_C + \mathcal{F^W}_C$$

$$\vec{\nabla}.\vec{\mathbf{v}}_L = 0$$

$$\rho = \rho(T, S, P)$$

# Wave-current coupling

WKB: Monochromatic wave model embedded in CROCO (no coupler):

- propagation/refraction
- Based on conservation of action and wavecrests
- Parametrizations for wave breaking and wave induced bottom drag
- No wave generation
- No wave-wave interactions
- Only monochromatic boundary forcing

Or, coupling with a spectral wave model (e.g. WW-III) with wave-averaged terms added to the ocean model equations

# Wave-current coupling

**O → W**

- Water level
- Currents (on the grid or north/east)

**W → O**

- Mean or Peak wave period/frequency
- Significant wave height
- Mean or Peak wave direction
- Mean wavelength
- Wave-to-ocean TKE flux
- Surface Stokes drift
- Orbital velocities
- Bernouilli head pressure
- Wave-to-ocean momentum flux
- Atmosphere-to-wave momentum flux

- Langmuir param ?
- NBQ : missing terms in VF equations ?

Porcile et al. 2023

New in v1.2
(or computed from monochromatic approx.)

To diagnose the part of energy used for wave growth

# Wave-current coupling

Porcile et al. 2023

**Bay of Somme (France) case study: comparison between monochromatic and spectral formulation of the wave-induced terms**

2WC+LM : spectral mean wavelength
2WC+BHD : spectral Bernoulli head monochromatic
(but mild conditions, in more energetic conditions the spectral Bernoulli head may have implications on the surface flow field, especially in the case of complex sea- state spectra)

~similar

2WC+FOC : spectral wave energy dissipation due to breaking

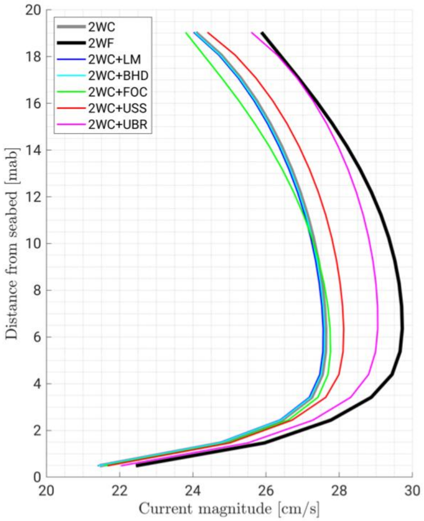
=> wave-induced effects close to the free-surface where it induces additional mixing

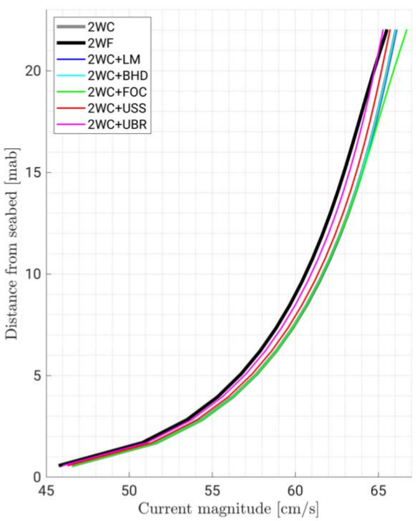
2WC+USS : Stokes drift (advection terms and vortex forces)

=> modifies the profile starting at the free-surface, but affecting the motion also deeper in the water column

2WC+UBR : near-bottom orbital velocity

=> increasing wave-induced effects near the seabed and shifting the overall profile due to an enhancement of bottom friction



# OWA and OW : consistency of momentum flux

**Améliorer la consistance de la bulk en couplage 3 modèles (et OW) :**

→ problématique : la bulk est calculée dans le modèle de vagues (prise en compte du spectre)
et dans le modèle d'atmosphère (ou d'océan) => 2 bulks

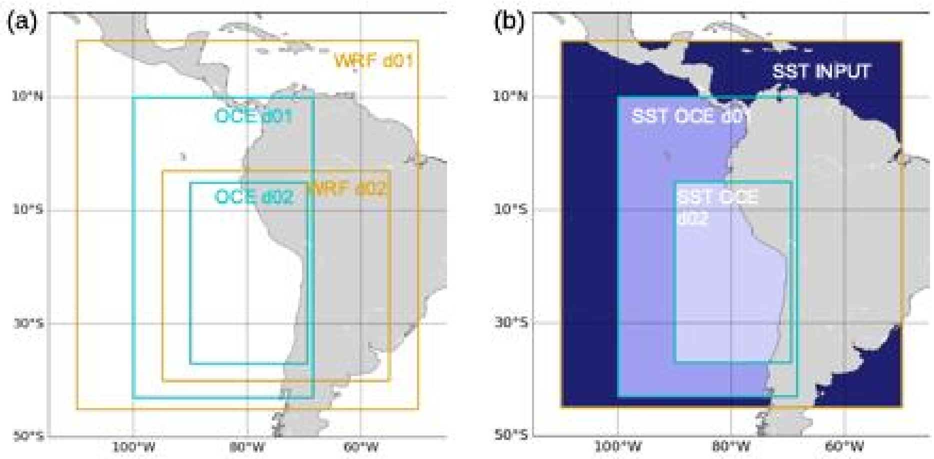
→ réflexion en cours pour n'avoir plus qu'une bulk, prenant bien en compte les effets des vagues
A → W : $u_*$, $\theta_u$ (angle du vent), $z_0$ et $\rho_a$
W → A : $\tau w$ (= ∬… la partie utilisée pour la croissance des vagues) ou autre chose $T_{ws}$, $H_s$ (cf travaux Marie-Noelle)
+ modifier dans module_sf_sfclay le calcul de $z_0$ en prenant en compte $\tau_w$ comme fait dans WW3
W → O : prendre en compte $\tau sa$

Atm $\tau a$
———————V——————————Λ————————-
vagues $\tau w$ = ∬… $\tau wo$ + $\tau sa$ + $\tau dbk$
————————————————V——————————-
Oce

Avec :
- $\tau a$ le stress calculé par l'atmosphère
- $\tau w$ (= ∬… la partie utilisée pour la croissance des vagues)
- $\tau sa$ le stress que WW3 génère pour avoir une dissipation de la houle qui correspond aux obs.
- $\tau wo$ le stress qui correspond au déferlement des vagues en océan profond
- $\tau dbk$ le stress lié au déferlement à la cote, résolu uniquement en littoral, sinon est perdu pour le système (frontières ouvertes dans WW3)

# Dealing with nesting

Possible to couple multiple domains → use of a « coupling mask »
+ with WRF moving nest : coupling on the parent domain (with interpolation from moving nest(s))



# Tools

Coupling toolbox philosophy and workflow:

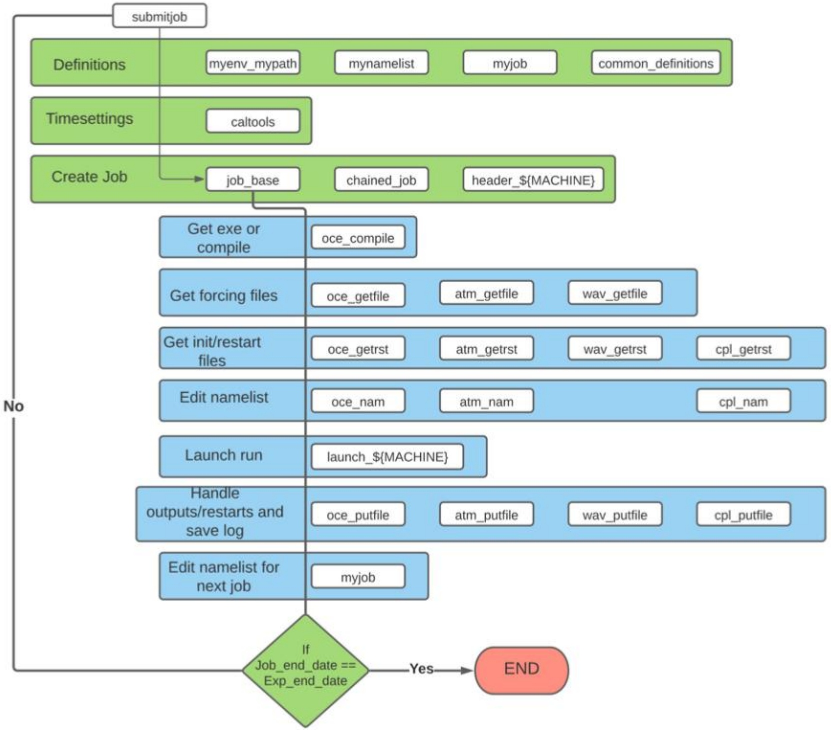
The user edit:

* **myenv_mypath.sh** : environment settings, and paths
* **mynamelist.sh** : settings for the experiment (which models, time stepping, input files…)
* **myjob.sh** : settings for the job (dates notably)

Then the user launch the job with **./submitjob.sh**

<u>The coupling toolbox manages:</u>

- CROCO compilation if requested
- getting models input files
- preparing OASIS restart files
- editing namelists (for models and OASIS)
- launching the run
- putting output files
- eventually looping for another job



# Tools

Coupling toolbox: configuration architecture

**$HOME/CONFIGS/YOURCONFIG**

- create_config.bash.bck
- myenv_mypath.sh ---------------- Environment file
- mynamelist.sh, myjob.sh ---------------- Settings for your run
- submitjob.sh ---------------- Script to launch the run
- SCRIPTS_TOOLBOX ---------------- Where all the toolbox scripts are*
- PREPRO ---------------- Directory for preprocessing
- OASIS_IN, CROCO_IN, WW3_IN, WRF_IN ---------------- Directories where input files of the different models are, such as namelist base files:
  - * croco.in.base
  - * namelist.input.base
  - * ww3_shel.inp.base
- jobs_YOUREXPER ---------------- Directory where job and log files are

**$WORKDIR/CONFIGS/YOURCONFIG**

- OASIS_FILES, CROCO_FILES, WW3_FILES, WRF_FILES — Directories where inputs of the different models are stored
- rundir
  - YOUREXPER_execute — where it is running, and where log files are
  - YOUREXPER_outputs — where outputs are
  - YOUREXPER_restarts — where restarts are

* More details: https://croco-ocean.gitlabpages.inria.fr/croco_doc/tutos/tutos.16.coupling.tools.html

# Roadmap for the working group

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**Enjeux :**

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| Echelles spatiales, multigrilles des différents modèles | → | Gestion du nesting en couplé |
| Robustesse, efficacité | → | OASIS |
| Inter-comparaison forcé/couplé (framework adapté) | → | Fichiers de forçage |
| Rendre accessible le couplage | → | Tools |

**A discuter et faire :**
Contribution du cisaillement de la dérive de Stokes au terme de production dans l'équation TKE de GLS
Termes supplémentaires vortex force en NH
Consistance des flux de moment (une seule bulk, impact de la dissipation de la houle…)
CFB → atm : doit-on prendre en compte Stokes ?
Vers le littoral : wet-dry et autres...
Tools : mieux splitter l'allocation calcul entre flux données (notamment post-pro et calcul)
pre-pro des forçages (flux / bulk / interp online)
XIOS3
Cas test couplé

# Appendices

# Wave-current coupling

**Stokes drift**

Porcile et al. 2023

Monochromatic formulation (WKB)

$$
\begin{aligned}
u_s &= \frac{A^2\sigma}{2\sinh^2(kD)}\cosh(2k(z+h))k_x, \\
v_s &= \frac{A^2\sigma}{2\sinh^2(kD)}\cosh(2k(z+h))k_y,
\end{aligned}
$$

$$w_s = -\int_{-h}^{z}\left(\frac{\partial u_s}{\partial x}+\frac{\partial v_s}{\partial y}\right)dz'$$

$A$ is the wave amplitude, $\sigma$ is its intrinsic frequency,

$\mathbf{k} = (k_x, k_y)$ is the wavenumber vector, $D$ is the mean depth.

From spectral wave model (WW-III)

$$(u_{ss}, v_{ss}) = \int\int \sigma\cosh(2kD)\frac{(k\cos(\theta_w), k\sin(\theta_w))}{\sinh^2(kD)}F(k,\theta_w)dkd\theta_w$$

$F(k,\theta)$ is the wavenumber-direction energy spectrum (with $\theta_w$ the mean wave direction)

$$(u_s(z_r), v_s(z_r)) = (u_{ss}, v_{ss})\left[\frac{1}{2k(1+e^{-4kD})}\right]$$

$$\frac{1}{z_{up}-z_{low}}\left[\left(e^{2k(z_{up}+h-D)}-e^{-2k(z_{up}+h+D)}\right)-\left(e^{2k(z_{low}+h-D)}-e^{-2k(z_{low}+h+D)}\right)\right]$$

where $z_r$, $z_{up}$ and $z_{low}$ represent respectively the vertical coordinate of the levels at RHO-points

# Wave-current coupling

**Bernouilli head (wave-induced pressure)**

Porcile et al. 2023

Monochromatic formulation (WKB)

$$\hat{\phi} = \frac{A^2\sigma}{4k\sinh^2(kD)} \int_{-h}^{z} \frac{\partial^2 \mathbf{k}\cdot\mathbf{v}}{\partial z'^2} \sinh(2k(z-z'))dz'$$

From spectral wave model (WW-III)

$$\hat{\phi} = g \int\int \frac{k}{\sinh(2kD)} F(k,\theta)\, dk\, d\theta$$

# Wave-current coupling

**Near-bottom wave orbital velocity (enhancement of bottom drag, mixing, streaming)** Porcile et al. 2023

$$\tau_{wc} = \tau_c \left(1 + 1.2\left(\frac{\tau_w}{\tau_w + \tau_c}\right)^{3.2}\right)$$

with current ($\tau_c$) and wave ($\tau_w$) related shear stresses :

$$\tau_c = \frac{\kappa^2}{\ln^2(z/z_0)}|\mathbf{u}|^2, \qquad \tau_w = \frac{\rho f_w u_w^2}{2},$$

and $f_w$ the wave friction factor :

$$f_w = 1.39\left(\frac{u_w}{\sigma_p z_0}\right)^{-0.52}$$

$u_w$ is the near-bottom wave orbital velocity, which is calculated :

Monochromatic formulation (WKB)

$$u_w = \sigma_p \frac{H_s}{2\sinh(kD)},$$

From spectral wave model (WW-III)

$$u_w = \sqrt{2}\left(2\int\int \frac{\sigma^2}{\sinh^2(kD)} F(k,\theta)\, dk\, d\theta\right)^{1/2}$$

# Wave-current coupling

## Wave-to-ocean energy flux

Porcile et al. 2023

In the wave-averaged momentum equations of the CROCO model, the acceleration induced by wave breaking enters as a body force :

$$\mathcal{F}^{w}_{u,v} = \frac{\epsilon_b}{\rho\sigma} k_{x,y} f_b(z),$$

where $f_b(z)$ : normalised vertical distribution function (i.e. vertical penetration of momentum)
$\epsilon_b$ : depth-integrated rate of wave energy dissipation due to wave breaking

### Monochromatic formulation (WKB)

Depth-induced breaking only.

A few formulation, including Battjes and Janssen (1978)

### From spectral wave model (WW-III)

$$\epsilon_b = \int\int S_{ds}(k,\theta) + S_{db}(k,\theta)\,dk\,d\theta,$$

$S_{db}$ : shallow-water dissipation (bathymetric breaking)
$S_{ds}$ : deep-water dissipation (white capping)

$$S_{db}(k,\theta) = -0.25\alpha Q_b f_m \frac{H_{max}}{E} F(k,\theta),$$

$Q_b$ : fraction of breaking waves $\quad \frac{1-Q_b}{-ln(Q_b)} = \left(\frac{H_{rms}}{H_{max}}\right)^2$

# Roadmap for the working group

Done :

interface avec OASIS et modèles incluant OASIS
+ interfaces de couplage dans WW3 et WRF
Bulk
ABL1D

To do :
Bulk
Pré-processing, gestion avancée de config. et de run, Code
Prise en compte de tous les termes de couplage (e.g. mélange (TKE, GLS, KPP), vortex force (y compris en NBQ), …)
XIOS3
Pression frontière OBC_PATM => M. Caillaud
Mieux splitter l'allocation calcul entre flux données (notamment pb concat fichiers de sorties, et post-pro type ounf) et calcul
Ajouter xtau, ytau dans restarts
CFB => atm : doit-on prendre en compte Stokes ?
Cpl OVA et littoral…
Prescription des forçages (flux / bulk / interp online)

# Coupling sequence

Exchange phase is called every time step but the effective exchanges are only performed at the defined coupling frequency