Towards ocean-atmosphere-wave coupled forecasts with AROME-NEMO-WW3: development, first results and future work

Cindy Lebeaupin Brossier\textsuperscript{1}, César Sauvage\textsuperscript{1}, Marie-Noëlle Bouin\textsuperscript{1}, Joris Pianeze\textsuperscript{2}, Jonathan Beuvier\textsuperscript{2}, Sylvie Malardel\textsuperscript{3}

\textsuperscript{1}CNRM, Université de Toulouse, Météo-France, CNRS
\textsuperscript{2}Mercator Océan International
\textsuperscript{3}LACy, UMR 8105 (Météo-France,CNRS, Université de La Réunion)
Chronological view of OAW coupling developments

- Ocean coupling over W Med Sea
  - AROME-NEMO WMED (2.5 km)
  - HyMeX case studies: IOP13, IOP16, SOP2 (Rainaud et al. 2017, qj rms), Lebeaupin Brossier et al. (2017, jgro)

- Wave coupling over NW Med Sea
  - AROME-WW3 (1.3 km)
  - HPE in 2016

- OA coupling over NW Med Sea
  - AROME-NEMO- WW3 (1.3 km)
  - HPE in 2016

- OA coupling for Indian Ocean (LACy)
  - AROME-NEMO
  - Tropical cyclones

- Ocean model design and OA coupling for AROME-France

- Runoff forcing on ocean
  - NEMO NWMED72 (1.3 km)
  - HyMeX case studies: SOP1 (Sauvage et al. 2019, om)

- OA coupling over Central Med Sea
  - MESONH-NEMO
  - Qendresa medicane

- OA coupling for eIBI (Mercator Ocean)
  - AROME-NEMO (2.5 km)
  - 7-day range HR ocean forecasts
The SURFEX-OASIS coupling interface

A collaborative work from a Technical Working Group
« O-A-W coupled systems using SURFEX-OASIS »
CNRM, Mercator Océan, LACY, LOPS, LAERO

ARPEGE[-Climat], ALADIN-Climat, AROME MESO-NH

Air-sea fluxes parameterization

SURFEX/OASIS-MCT

CTRIP

NEMO
SYMPHONIE
MARS3D

ocean

waves

WAVEWATCH III

rivers

atmosphere
The SURFEX-OASIS coupling interface

A collaborative work from a Technical Working Group
« O-A-W coupled systems using SURFEX-OASIS »
CNRM, Mercator Océan, LACY, LOPS, LAERO

SURFEX/OASIS-MCT
Air-sea fluxes parameterization

ARPEGE[-Climat], ALADIN-Climat, AROME
MESO-NH

NEMO
SYMPHONIE
MARS3D

CTRIP

ocean

waves

rivers

AROME-France / NEMO-NWMED72 / WW3

AROME-FR:
- cy41t1 with SURFEX v7.3 (+new sea surface fluxes param: WASP)
- no assimilation (dynamical adaptation)
- $\Delta x,y = 1.3$ km [1440 x 1536]
- 90 vertical levels
- IC: AROME analysis
- LC: ARPEGE forecast

NEMO: NWMED72
- v3.6_STABLE
- no assimilation
- $\Delta x,y \sim 1/72^\circ$ [-1.2km] over NW Med Sea
- 50 vertical z-levels
- IC/LC : PSY4 global daily analysis (1/12°) or 7day- spin-up

WW3:
- same horizontal domain as NEMO (1/72°)
- IC: WW3 experiment
- LC: 8 wave spectra from MARC

OASIS coupler:
- fields exchanged every 1 hr
- bilinear interpolations
- no O-W coupling
Heavy precipitation over Hérault: 300 mm in 24h
Strong easterly winds with gusts above 100 km/h
High sea state with significant height up to 6 m
## Numerical experiments:

<table>
<thead>
<tr>
<th></th>
<th>models</th>
<th>SST outside NWM</th>
<th>SST over NWM</th>
<th>current (over NWM)</th>
<th>Tp (over NWM) in WASP</th>
</tr>
</thead>
<tbody>
<tr>
<td>AY</td>
<td>AROME</td>
<td>PSY4 global daily analysis</td>
<td>null</td>
<td>f(Ua)</td>
<td></td>
</tr>
<tr>
<td>AYSSTatl</td>
<td>AROME</td>
<td>AROME analysis</td>
<td>PSY4 global daily analysis</td>
<td>null</td>
<td>f(Ua)</td>
</tr>
<tr>
<td>AWF</td>
<td>AROME</td>
<td>PSY4 global daily analysis</td>
<td>null</td>
<td>WW3 run outputs</td>
<td></td>
</tr>
<tr>
<td>AWC</td>
<td>AROME-WW3</td>
<td>PSY4 global daily analysis</td>
<td>null</td>
<td>coupled</td>
<td></td>
</tr>
<tr>
<td>AOW</td>
<td>AROME-WW3-NEMO</td>
<td>AROME analysis</td>
<td>null</td>
<td>coupled</td>
<td></td>
</tr>
</tbody>
</table>

*Initially: NEMO spin-up for 12 Oct., then AOW D-1 +24h forecast*
WASP:

\[ C_d = f(z_0) \quad C_H = f(z_0, z_0 h) \]

(Ident for \( C_e \))

\( z_0 \) and \( z_{on} \): roughness lengths (drag and thermal)

Charnock’s relationship

\[ z_0 = \frac{\alpha_{ch} \cdot u_\ast}{g} + \frac{\beta \cdot \nu}{u_\ast} \]

Charnock’s coefficient

\[ \alpha_{ch} = A \chi^B \]

Wave age

\[ \chi = \frac{C_p}{U_a} \]

\[ C_p = g \cdot \frac{T_p}{2\pi} \]

<table>
<thead>
<tr>
<th>( \chi &lt; 0, 8 )</th>
<th>0, 8 &lt; ( \chi &lt; 1, 2 )</th>
<th>( \chi &gt; 1, 2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>young sea</td>
<td>developed sea</td>
<td>swell</td>
</tr>
</tbody>
</table>

wind sea
Wave coupling: impacts the low-level dynamics

**AWF vs AY**

- U10 decreases by 7% on average
Wave coupling: impacts on rainfall forecast

- Small changes in intensity
  24h amounts (13/10-14/10):
  - Hérault:
    - 56.8 mm (max 271 mm)
    - 58 mm (max 278 mm)
    - 58.8 mm (max 273 mm)
  - Offshore:
    - 43.5 mm (max 188 mm)
    - 43.4 mm (max 187 mm)
    - 42.2 mm (max 214 mm)

- Impacts on localisation
Ocean coupling: SST change induced by initialisation

AROME-France / NEMO-NWMED72 / WW3

AOW exp

13 oct 2016 00UTC +1h

AOW exp differences with AWC (=PSY4)

13 oct 2016 00UTC +1h
Ocean coupling: heat flux modifications

AOW vs AWC

- Increase in heat fluxes → due to initial SST
- Smoothing effect → due to surface cooling reproduce by ocean coupling
Eastward displacement of heavy rainfall

**Intensification**
24h amounts (13/10-14/10):

- **Hérault:**
  - 58.4 mm (max 264mm)
  - 56.8 mm (max 271mm)
  - 58.8 mm (max 273mm)

- **Offshore:**
  - 45.1 mm (max 228mm)
  - 43.5 mm (max 118mm)
  - 42.1 mm (max 214mm)
Development of an ocean-atmosphere coupled configuration at high-resolution (1/36°) for ocean forecasts on North-Eastern Atlantic Ocean and Western Mediterranean Sea (= IBI36 zone extended eastwards)

**MERCATOR’s objectives:**
- Improve the ocean high-resolution forecasts (higher resolution of the atmospheric forcing and consistency with the ocean dynamics)
- Be able to provide high-resolution forecasts for the whole Western Med Sea, notably fully covering Corsica’s coasts (eastwards extension of IBI36) and improve the representation of the Northern Current (originating from the Ligurian Sea)
- Improve the initialisation of coupled models using the AROME / NEMO systems (consistency with large scale models used at lateral boundaries)
- Start preparing assimilation methods for operational coupled models

**AROME: new domain**
- cy43t2 (SFX v8_0), same atmos. physics as oper AROME-France
- sea surface fluxes parameterization (COARE 3.0)
- No assimilation (dynamical adaptation)
- ∆x,y = 2.5 km [1285 x 1789]
- 90 vertical levels
- IC/LC: ARPEGE or IFS

**NEMO: eNEATL36**
- V3.6, same physics as NEMO-NEATL36 (IBI36 oper)
- No assimilation
- ∆x,y ~ 1/36° [1294 x 1894]
- 50 vertical z-levels
- IC/LC : mix between PSY4 and IBI36
12-18 Oct 2018
→ successive severe events over the area with potential high OA interactions
- **Callum storm**: Strong wind and rainfall over Wales
- **Leslie tropical cyclone**: Strong wind over Portugal
- **Leslie & Michael cyclone remnants**
- **Aude heavy precipitation and flash-flood**: 295.5 mm in 12 hours in Trèbes

Kendon et al. 2019 (10.1002/joc.6213)
Caumont et al. 2021 (10.5194/nhess-21-1135-2021)
Experiments:

- **OA coupled experiment**: OA
- **Atmosphere-only exp** persistent SST coming from OAREF at t=0: **ARO**
- **Ocean-only experiment with IFS atmospheric forcing**: **OCE-ifs**
- **Ocean-only experiment with ‘ARO’ atmospheric forcing**: **OCE-aro**

SST evolution in OA (and comparison with ARO)
Summary of the results on the weather forecast side: OA-ARO
Conclusion

Improved interface for OAW coupling in SURFEX/AROME:
→ interface with OASIS since v8_0 for OA (and OAW in the future v9)
→ available since cy38, insertion in the official release planned for cy48 (work by S. Malardel)
→ sea surface flux computation taking sea state into account (WASP, also COARE) in forced or coupled modes

Impact on weather forecast:
→ evolving sea surface conditions with fine-scale structures: more realistic
→ ocean coupling (and initialisation) have main impacts on heat and moisture fluxes and indirectly on low-level circulation
→ wave coupling strongly impacts the low-level wind
→ both couplings induce modifications of the weather forecast but only few case studies…
Perspectives

Ocean initialisation and uncertainties propagation

→ build a NEMO configuration suitable for coupling with AROME-France (domain, common physics with Mercator regional system) and evaluate various initial conditions (daily mean 1/12°, 1/36°, instantaneous fields) and impacts in ocean-only experiments (Master internship 2021)

→ investigate the propagation of ocean perturbations (initial fields or boundary conditions) in the atmospheric forecast (and vice-versa) with the coupled system (PhD thesis 2021-2024)

Towards a regional “Earth”/coupled system for NWP

→ have and maintain an OA coupled model close to the operational NWP system, serving as a basis for the insertion of other components (in particular wave coupling to be pursued in collaboration, aerosols, hydrology, etc.), ready to be used for coupled assimilation tests if needed, fully usable for research applications, and in preparation for future AROME-based RCSM (CNRM « pre-project »)
Thank you for your attention!

contact: cindy.lebeauvin-brossier@meteo.fr