The coupled ocean-atmosphere model at ECMWF: overview and technical challenges

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Overview of talk:

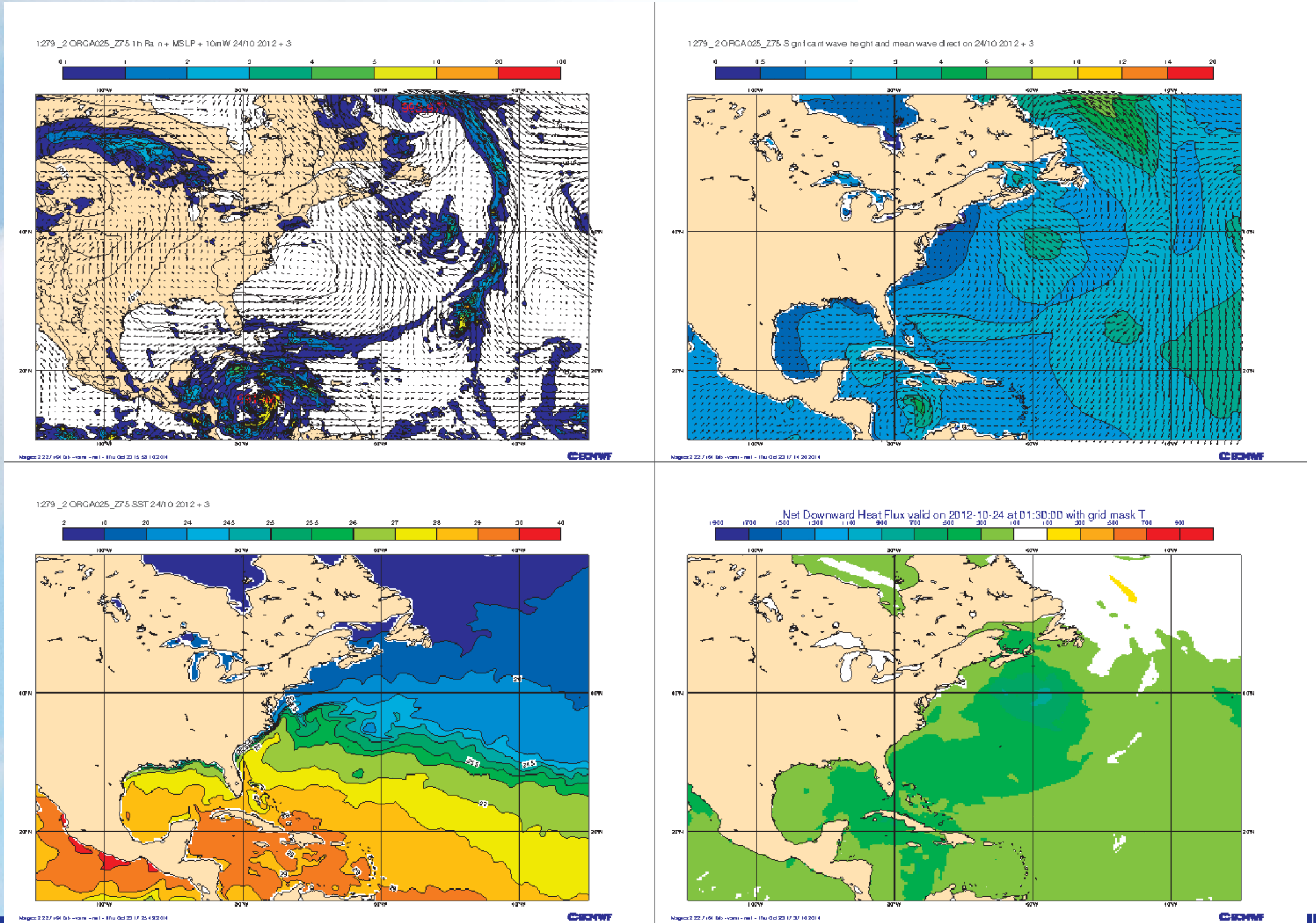
- Baseline:
  - The focus of this talk is going to be on coupling of IFS and WAM to NEMO
  - The IFS to WAM coupling is old news
- Motivation:
  - Why do we need to couple the ocean to the atmosphere in the first place?
  - A brief history of coupled model setup at ECMWF
    - Technologies used for coupling in the past
- The current coupled model based on IFS-WAM-NEMO:
  - How does it work and especially how do we glue the IFS+WAM together with the NEMO model.
  - Scalability of the coupled model
- Technical challenges:
  - Communicating fields between grids
  - Initialization of the coupled system
- Conclusions and outlook

Motivation for coupled modelling.

Why do we need to couple an ocean model to our atmosphere model?

- The ocean is the lower boundary for atmosphere for a large part of the earth
- Accurately modelling this lower boundary should give feedback to the atmosphere
- For long range predictions like seasonal forecasting and monthly forecasting this is very important
  - ENSO
- For medium range forecasting the ocean state (including sea-ice) can change on a daily time scale
  - Ice modelling
  - Hurricane feedback to/from the ocean
- Today we use a coupled model for the following systems:
  - The ensemble prediction system (ENS) from day 0 to 15 and the monthly extension to day 32 twice per week
  - The seasonal forecasting system

Future medium range applications of a coupled model: Hurricanes



A short history of coupled ocean-atmosphere modelling at ECMWF.

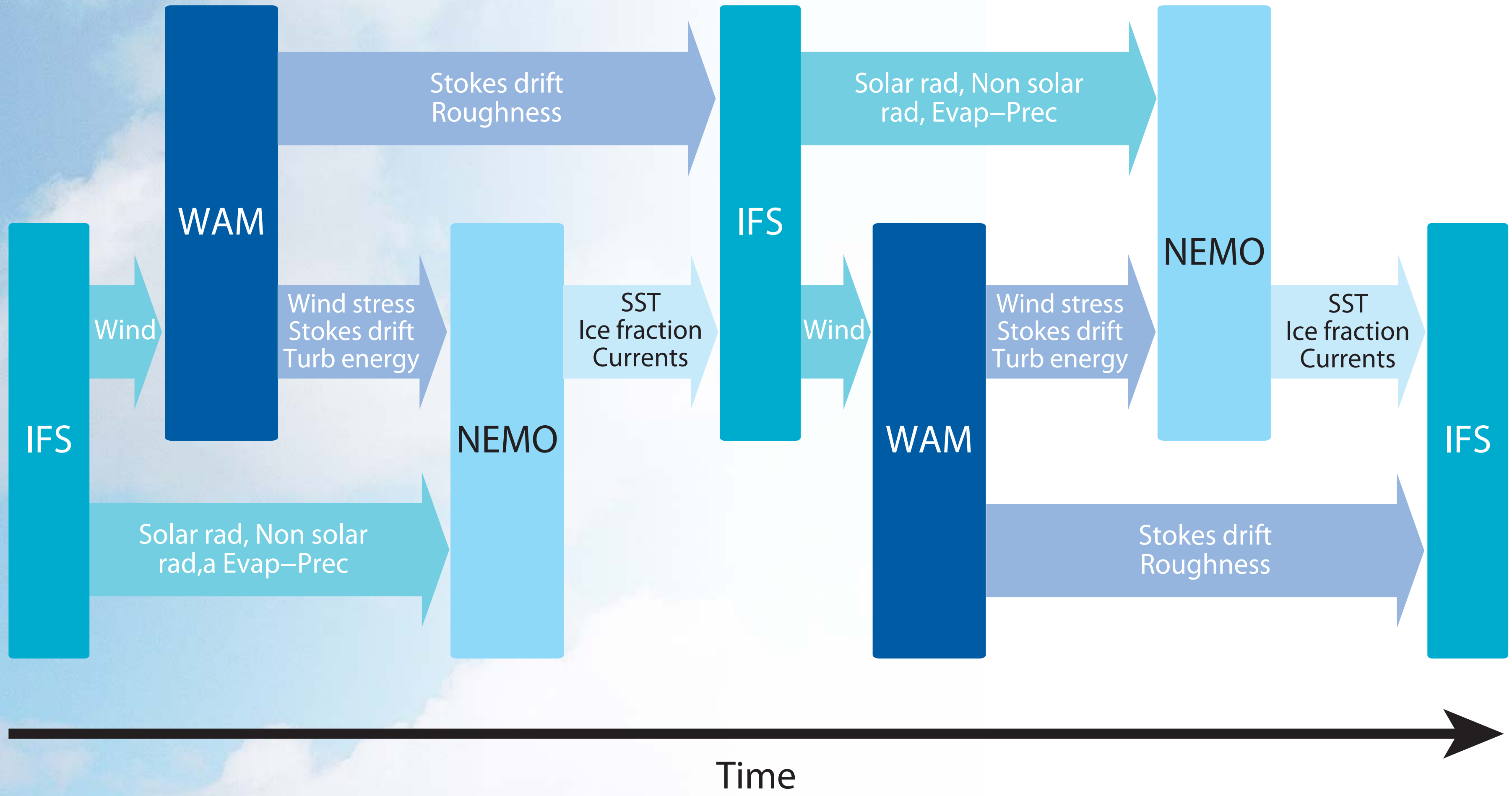
- IFS coupled to HOPE (from around 1997).
  - OASIS2 based on coupling via files/pipes
  - Seasonal: System 1 to 3
  - Monthly forecasting
    - Originally separate system
    - Became part of VarEPS (now ENS) coupled in leg B (day 10 to 15) and leg C (beyond day 15) in March 2008
- IFS coupled to NEMO (from November 2011)
  - OASIS3 based on coupled via MPI using MPMD execution
  - Seasonal system 4 + VarEPS/ENS
- IFS coupled to NEMO in a single executable (from November 2013 in ENS).
  - No external coupler
  - Coupling between the WAM component and NEMO
  - ENS system coupled in all 3 legs (coupling from day 0)

The current and future coupled system

Current coupled system:

- Design principle: the atmosphere and wave models don't know anything about the inner workings of NEMO
  - The coupling layer have access to all NEMO F90 modules (*e.g*. data), but only accepts data from IFS/WAM as arguments
    - Coupling fields to/from NEMO is passed as subroutine arguments to this layer in IFS/WAM
    - Grid information from IFS/WAM needs to passed as arguments as well
- All regridding is done within the interface layer:
  - Interpolation weights are computed outside the model and read from a file
  - The interpolation is done in parallel with minimum source field information communicated to the individual MPI tasks
    - If destination points *a* and *b* on task *N* both needing source point *c* from task *M* then it is only sent to task *N* once
- Model version:
  - NEMO version 3.4.1 (with LIM2)
  - Initially in CY40R1 of the IFS and updated with each IFS cycle

Schematic overview of coupled system without the LIM2 ice model



The LIM2 model needs additional fields from the IFS

Extract of source code for the coupled model on the IFS side: Control interface

```
IF (LNEMOCOUP) CALL ININEMO
DO JSTEP=NSTAR2,ISTOP
  <<BORING ATMOSPHERE STUFF>>
  IF (LLWVTIME) THEN
    CALL WVCOUPLE(TSTEP,NSTPW,LLSTOP,LLWRRW)
  ENDIF
  IF(NFRCO /= 0 .AND. LNEMOCOUP .AND. LMCC04) THEN
    IF(MOD(NSTEP,NFRCO) == 0) THEN
      IF (LWCOU) THEN
        CALL UPDNEMOFIELDS(LWSTOKES)
        CALL UPDNEMOSTRESS
      ENDIF
      CALL COUPLNEMO(NSTEP)
    ENDIF
  ENDIF
ENDDO
```

Extract of source code for the coupled model on the IFS side: Coupling and running of NEMO

- How data to NEMO is transferred, the NEMO time-stepped and fields received with the IFS
  - Interface routines are in blue

```
! Update NEMO forcing fields
CALL NEMOGCMCOUP_UPDATE( MYPROC-1, NPROC, MPL_COMM, NGPTOT, &
     &                   ZSTRSU, ZSTRSV, ZFRSOS, ZFCHAS, ZFHUMS, &
     &                   KSTEP, LNEMOFLUXNC )
! NEMO time stepping
DO JSTPNEMO=NEMOCSTEP,NEMOCSTEP+NEMONSTEP-1
  ! Advance the NEMO model 1 time step
  CALL NEMOGCMCOUP_STEP( JSTPNEMO, IDATE, ITIME )
ENDDO
! Update IFS coupling fields
CALL NEMOGCMCOUP_GET( MYPROC-1, NPROC, MPL_COMM, &
      &               NGPTOT, ZGSST, ZGICE, ZGUCUR, ZGVCUR )
```

- In NEMOGCMCOUP_UPDATE the data are regridding and relevant variables in NEMO updated
- The routine NEMOGCMCOUP_STEP basically just call the standard NEMO time step routine
- In NEMOGCMCOUP_GET the NEMO fields are regridded nto the arguments variable

Scalability of the coupled model.

- Scalability runs for a 10 day period of
  - ENS resolution (T639_L91 or around 31 km)
    - The ocean and atmosphere is about equal in cost
    - Up to 1200 cores tested
  - HRES resolution (T1279_L137 or around 15 km)
    - The ocean is cheap compared to the atmosphere
    - Up to 3600 cores tested
- All run was done on the production Cray XC-30 systems at ECMWF means interference from other running jobs on file system load *etc*
  - Initialization is ignored (but I will get back to that later)
  - No output, but normal input
- Coupling overhead were investigated by changing the frequency of coupling
  - This changes the solution, but frequent coupling is a goal
  - This was done without the ice model for reasons explained later

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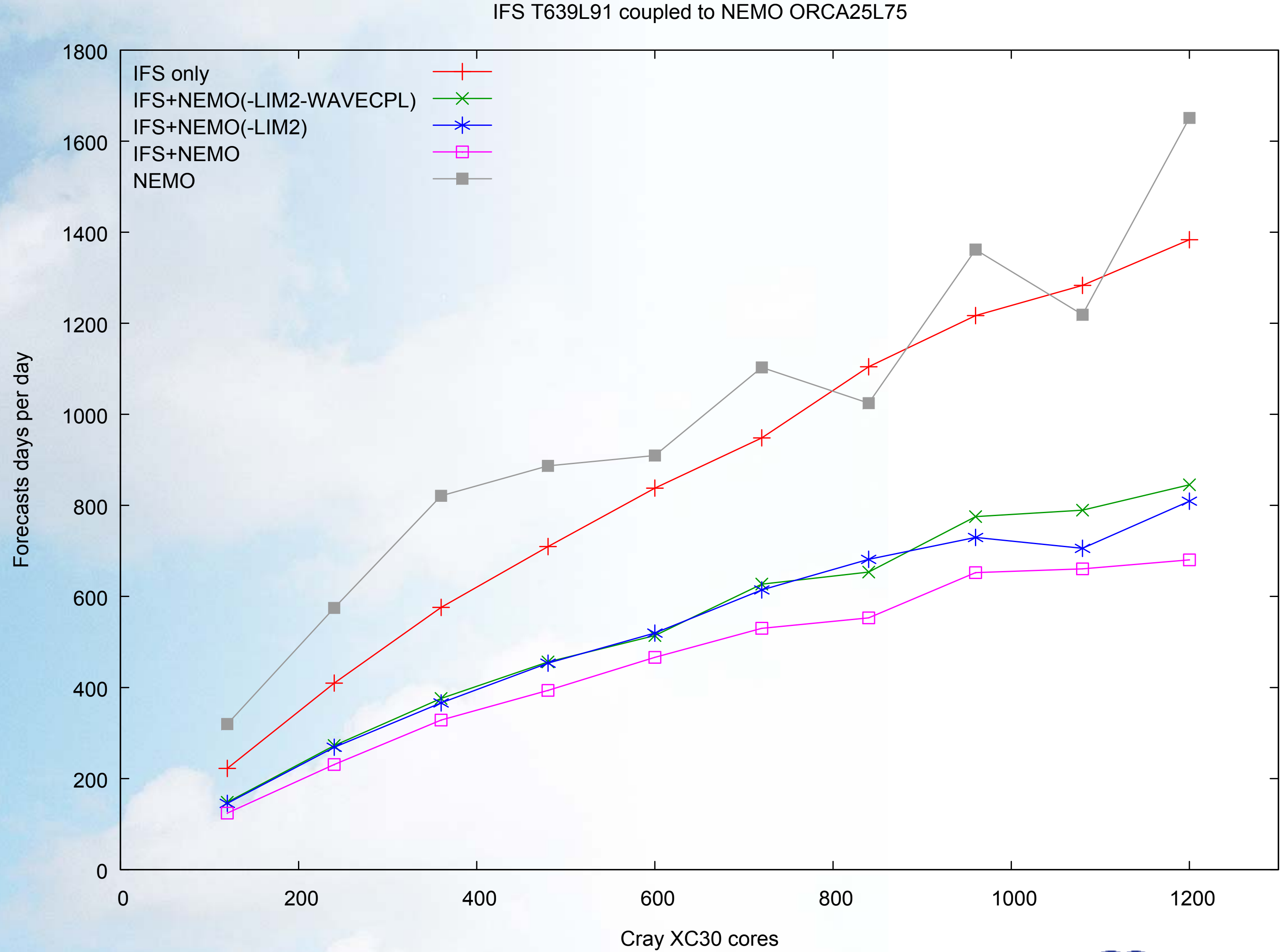
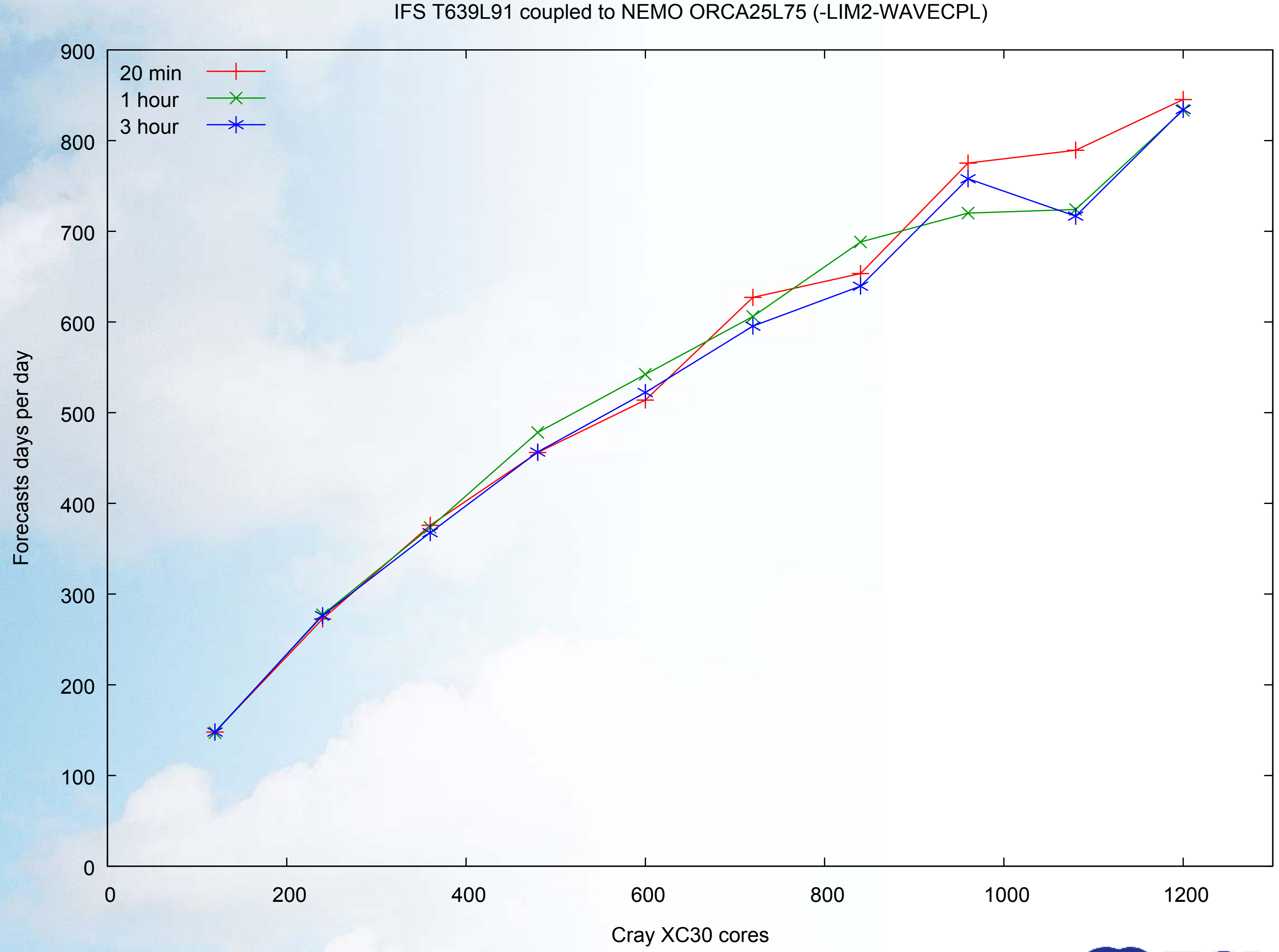
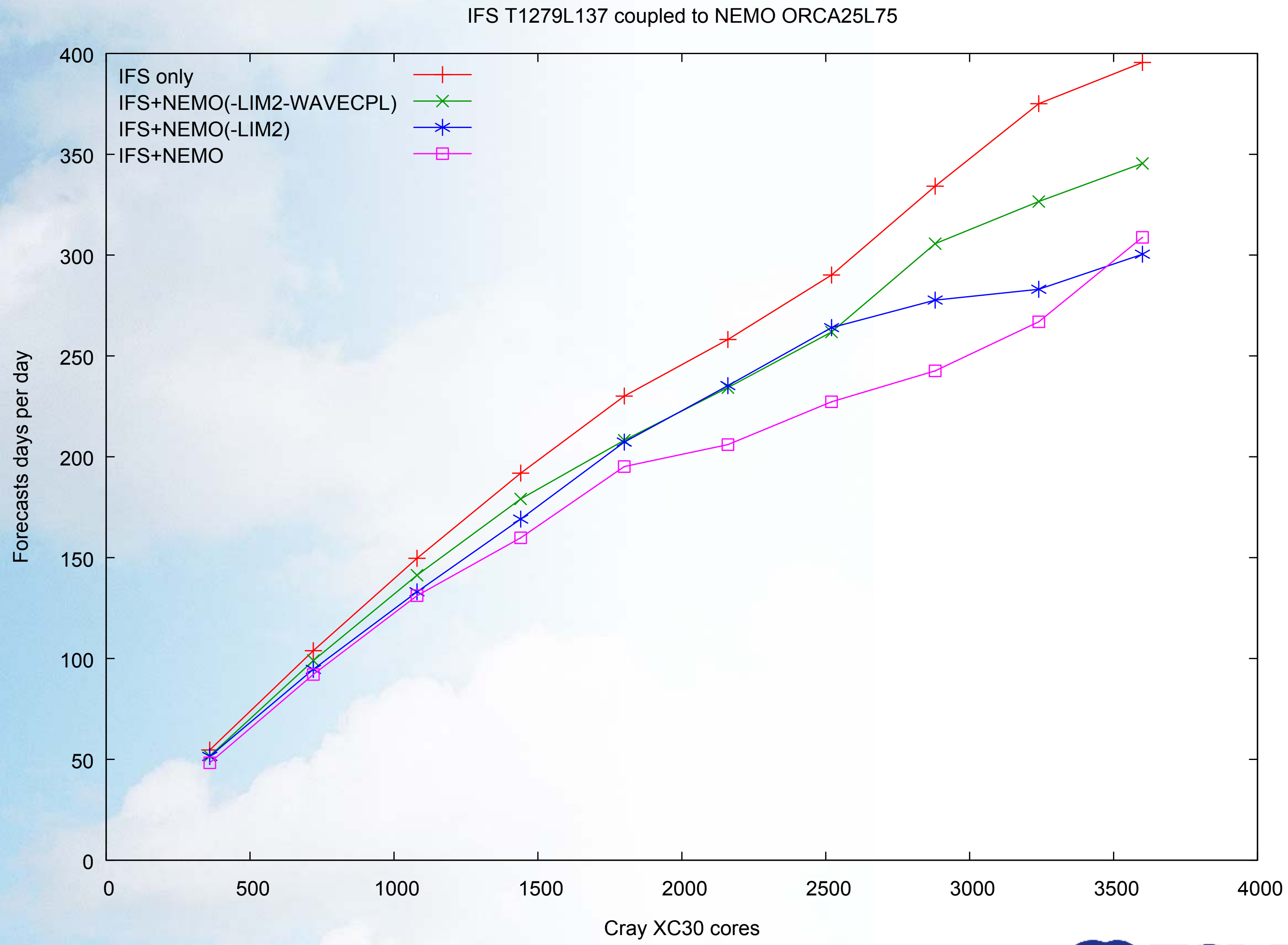
Scalability of the coupled model at ENS resolutions



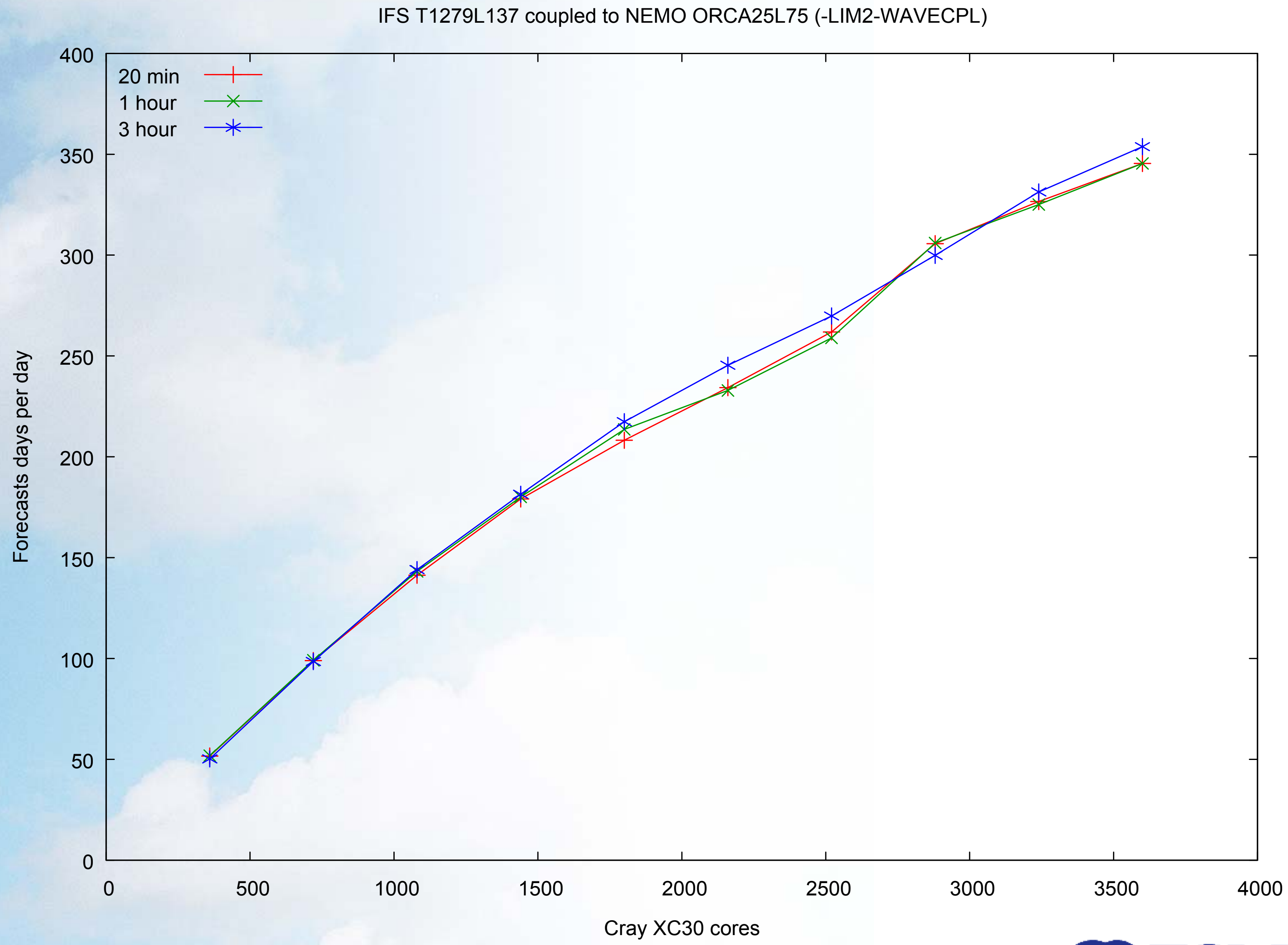
Effect of coupling frequency: No measureable slowdown.



Scalability of the coupled model at HRES resolutions



Still no real slowdown



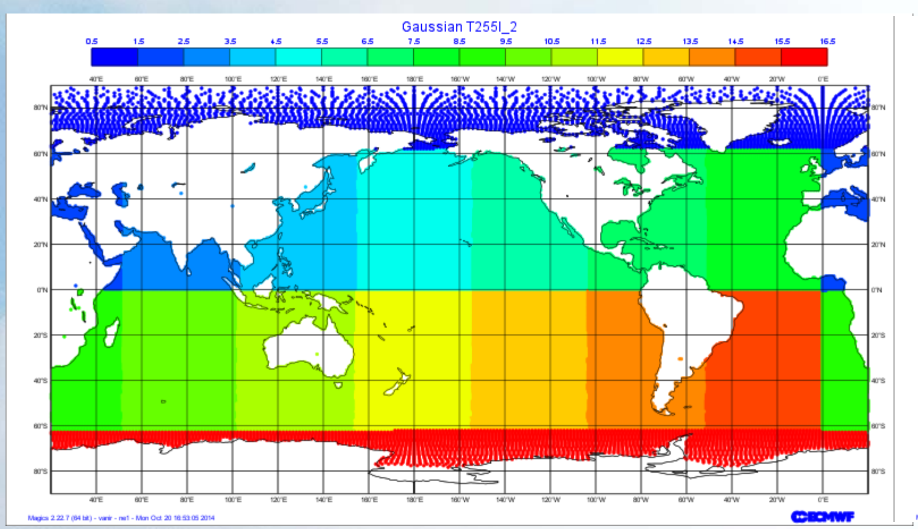
Scalability observations

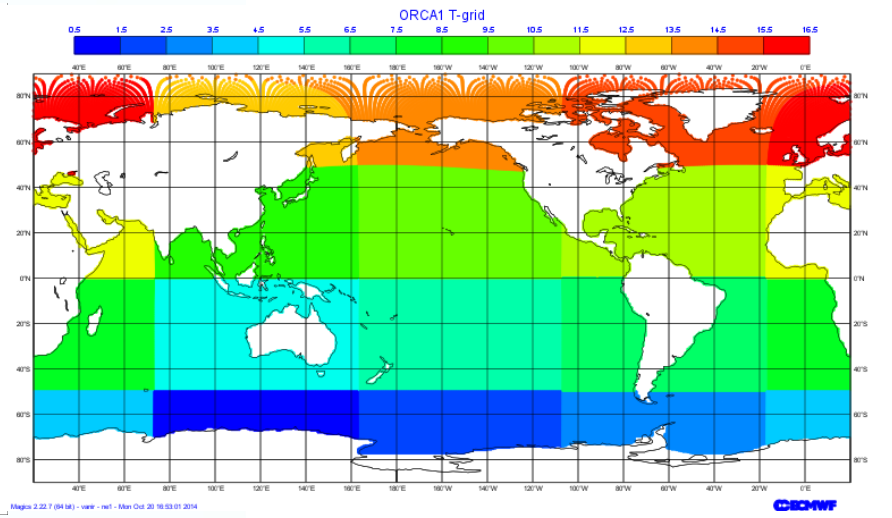
- The coupled model scale reasonable well, but there are room for improvements (as always)
  - In principle we could implement a coupled HRES system today (in terms of run times only)
- Very little overhead in the actual coupling on a production system
  - More frequent coupling should be more expensive
  - A dedicated system might reveal some difference
- High frequent coupled current means calling the ice model more frequent since it is called at every coupling step
  - Makes physical sense since the forcing fields of the ice model are updated
    - But at an added cost

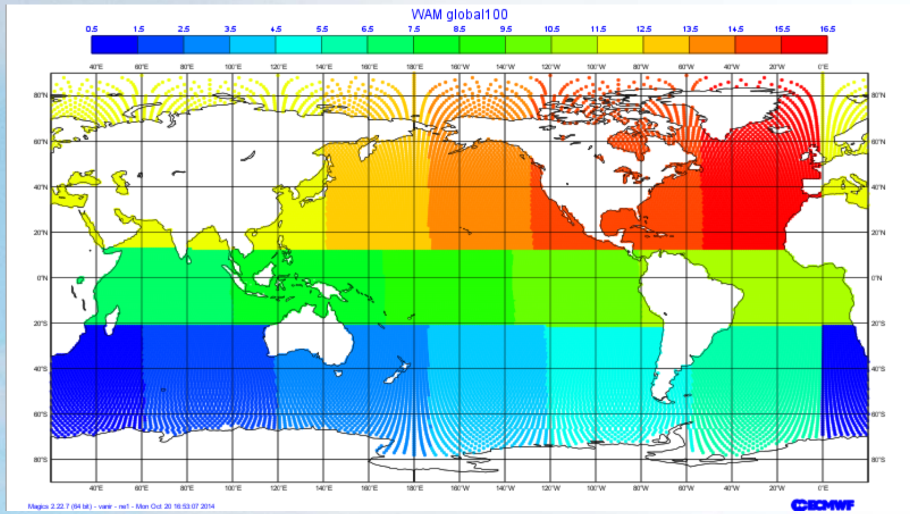
Challenges for our coupled model

1. Grids don’t overlap
2. Initialization of the coupling

Challenges 1.1: The grids of the model components are different and have different parallel decomposition

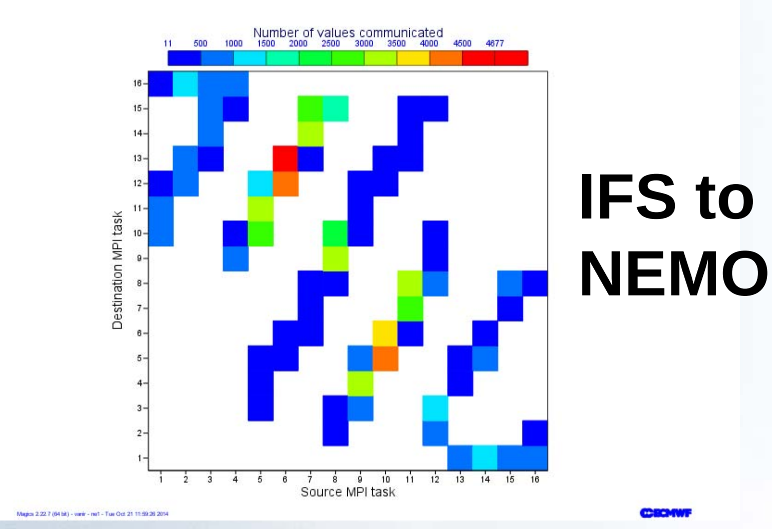




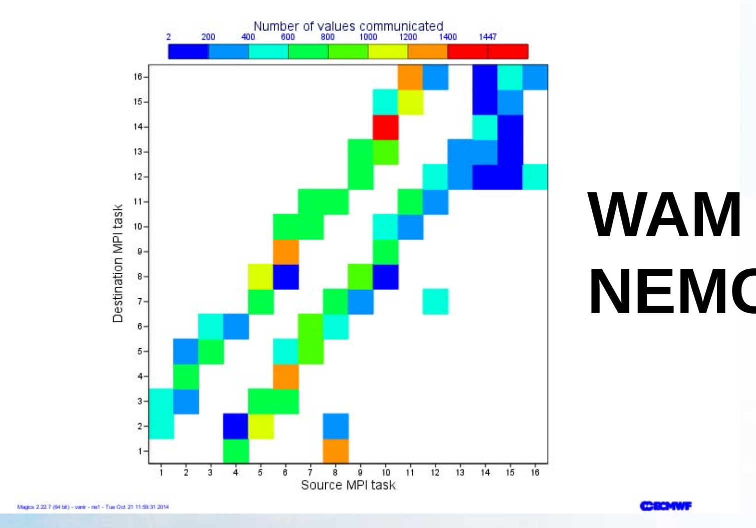


- Top left Gaussian N128 reduced atmosphere grid
- Top right ORCA1 ocean grid
- Bottom left 1.0 degree reduced wave grid
- 16 domains for all grids

Challenges 1.2: communication patterns.



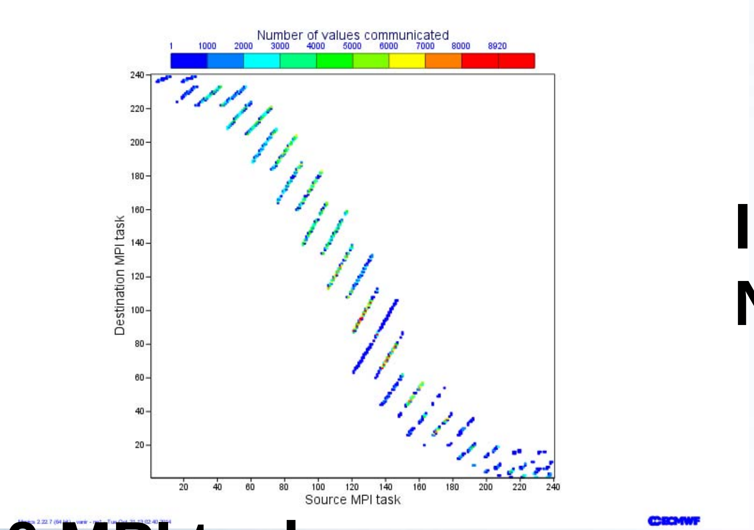
IFS to NEMO



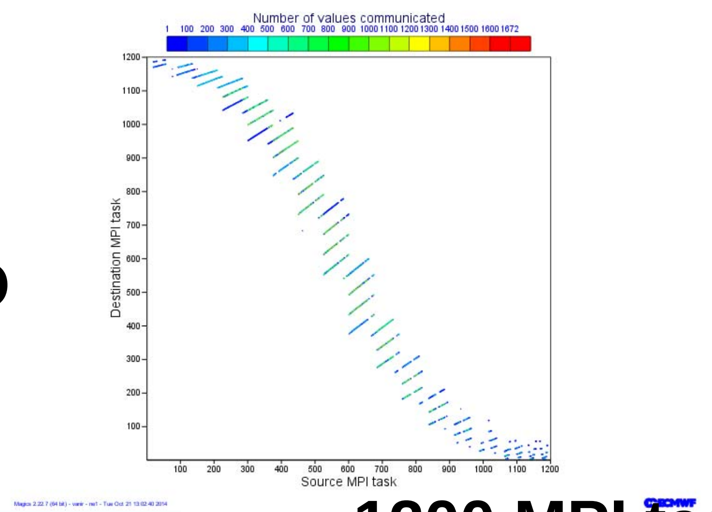
WAM to NEMO

- Grids from previous slide
- 16 point stencil used in interpolation
- Little overlap of areas means all interpolations needs communication
- Short messages of the order of Kbytes
- Packing all fields together could be done to decrease the number of exchanges
  - Especially important when coupling with the LIM ice model
- A solution could be to reshuffle domains in NEMO, but that would require changes to the halo exchange

Challenges 1.3: T1279+global025 to ORCA025

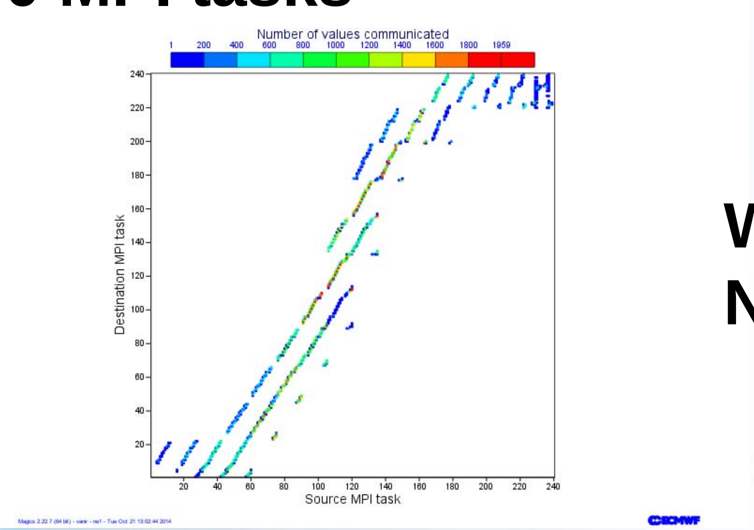


IFS to NEMO

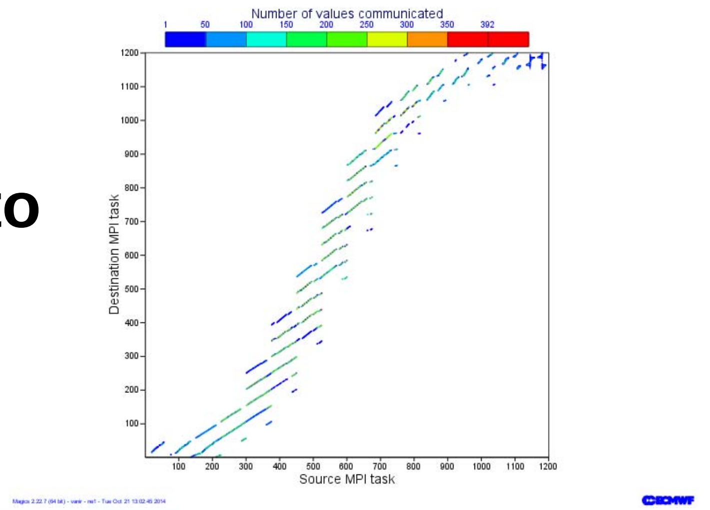


240 MPI tasks

1200 MPI tasks



WAM to NEMO



Challenges 2.1: Initialization of the coupled model first version.

- The first time steps of the T1279l_2_Z137 coupled to ORCA025_Z75 on 1200 MPI tasks with 6 threads/tasks.

```
15:01:00 000000000 CNT3      -999    23.23   23.23    5.18      0:14      0:23 0.00000000000000E+00
15:09:41 A00000000 STEP0        0  2864.78 2864.78  526.60     47:59      9:09 0.28922730264112E-04
15:09:41 0AA000000 STEP0        0     0.01    0.01    0.00     47:59      9:09 0.28922730264112E-04
15:09:42 0AAA00AAA STEP0        0     0.54    0.54    0.18     48:00      9:09 0.28922730264112E-04
15:09:44 0AAA00AAA STEP0        1    12.84   12.84    2.64     48:12      9:12 0.29212296020822E-04
15:13:54 0AAA00AAA STEP0        2  1366.70 1366.70  249.75     70:59     13:22 0.29499942932315E-04
15:14:33 0AAA00AAA STEP0        3   210.28  210.28   39.09     74:29     14:01 0.29853445010196E-04
15:14:34 0AAA00AAA STEP0        4     8.01    8.01    1.35     74:37     14:02 0.30156426220388E-04
15:14:37 0AAA00AAA STEP0        5    13.09   13.09    2.21     74:50     14:04 0.30412906653708E-04
15:14:38 A00000000 STEP0        6     7.75    7.75    1.30     74:58     14:06 0.30631624190308E-04
15:14:38 0AA000000 STEP0        6     0.00    0.00    0.00     74:58     14:06 0.30631624190308E-04
15:14:38 0AAA00AAA STEP0        6     0.98    0.98    0.17     74:59     14:06 0.30631624190308E-04
15:14:41 0AAA00AAA STEP0        7    18.06   18.06    3.03     75:17     14:09 0.30818912985184E-04
15:14:42 0AAA00AAA STEP0        8     7.60    7.60    1.28     75:25     14:10 0.30984119227123E-04
15:14:45 0AAA00AAA STEP0        9    12.32   12.32    2.07     75:37     14:12 0.31135002405381E-04
15:14:46 0AAA00AAA STEP0       10     7.60    7.60    1.28     75:45     14:14 0.31274700232161E-04
15:14:48 0AAA00AAA STEP0       11    11.92   11.92    2.01     75:57     14:16 0.31406548637423E-04
15:14:49 A00000000 STEP0       12     7.76    7.76    1.31     76:04     14:17 0.31532197346928E-04
15:14:49 0AA000000 STEP0       12     0.00    0.00    0.00     76:04     14:17 0.31532197346928E-04
15:14:49 0AAA00AAA STEP0       12     0.94    0.94    0.16     76:05     14:17 0.31532197346928E-04
```

Contains initializion of IFS-NEMO coupling

Contains initializion of WAM-NEMO coupling

- For a 60 minutes operational deadline for a 10 day forecast we can not afford to spend 13 min initializing the model

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Challenges 2.2: Initialization of the coupled model second version.

- Initial run. Writing of redistribution information:

```
14:40:03 000000000 CNT3       -999    34.86    34.86     7.00      0:07      0:21 0.00000000000000E+00
14:47:42 A00000000 STEPO         0  2580.85  2580.85   465.48     43:08      8:06 0.28922730264112E-04
14:47:42 0AA000000 STEPO         0     0.00     0.00     0.00     43:08      8:06 0.28922730264112E-04
14:47:42 FULLPOS-B DYNFPOS       0     0.54     0.54     0.12     43:09      8:06 0.28922730264112E-04
14:47:44 FULLPOS-S DYNFPOS       0     9.15     9.15     1.80     43:18      8:08 0.28922730264112E-04
14:47:53 0AAA00AAA STEPO         0    47.81    47.81     9.46     44:06      8:17 0.28922730264112E-04
14:47:56 0AAA00AAA STEPO         1    14.24    14.24     2.61     44:20      8:20 0.29211277546594E-04
14:51:18 0AAA00AAA STEPO         2  1117.01  1117.01   201.80     62:57     11:42 0.29492720992204E-04
14:51:44 0AAA00AAA STEPO         3   147.58   147.58    26.49     65:24     12:08 0.29839437592746E-04
14:51:46 0AAA00AAA STEPO         4     7.80     7.80     1.33     65:32     12:10 0.30137062692285E-04
```

Similar overheads

- Subsequent runs. Reading of redistribution information:

```
15:03:52 000000000 CNT3       -999    17.99    17.99     6.00      0:13      0:21 0.00000000000000E+00
15:05:55 A00000000 STEPO         0   683.55   683.55   129.06     11:37      2:30 0.28922730264112E-04
15:05:56 0AA000000 STEPO         0     0.14     0.14     0.03     11:37      2:30 0.28922730264112E-04
15:05:56 FULLPOS-B DYNFPOS       0     0.66     0.66     0.14     11:38      2:30 0.28922730264112E-04
15:05:59 FULLPOS-S DYNFPOS       0    15.62    15.62     3.09     11:53      2:33 0.28922730264112E-04
15:06:08 0AAA00AAA STEPO         0    44.48    44.48     8.80     12:38      2:42 0.28922730264112E-04
15:06:10 0AAA00AAA STEPO         1    14.20    14.20     2.66     12:52      2:45 0.29211277546594E-04
15:06:26 0AAA00AAA STEPO         2    88.68    88.68    15.97     14:21      3:01 0.29492720992204E-04
15:06:54 0AAA00AAA STEPO         3   152.06   152.06    27.32     16:53      3:28 0.29839437592746E-04
15:06:55 0AAA00AAA STEPO         4     7.96     7.96     1.37     17:01      3:29 0.30137062692285E-04
```

Much better (but not great)

- Initialization of NEMO is an issue also in NEMO standalone.

Conclusions and outlook

- The single executable coupled model works reasonable well for the current operational resolutions
  - As always: improvements are possible
- With our setup the coupled model almost don’t feel like a coupled model
  - No fundamental technical difference between calling the atmospheric physics and the ocean model (besides the regridding)
- It have been used for ensemble medium range forecasting (ENS) for close to a year now with a low resolution (1 degree) configuration
  - Some forecasts seems to having benefitted from the coupling, but some problems has also been highlighted
- Work on integrating the coupled model in other systems has been done or is ongoing
  - Weakly coupled data assimilation prototype has developed in the context for reanalysis
  - More work on high resolution coupled modeling will be done in the near future

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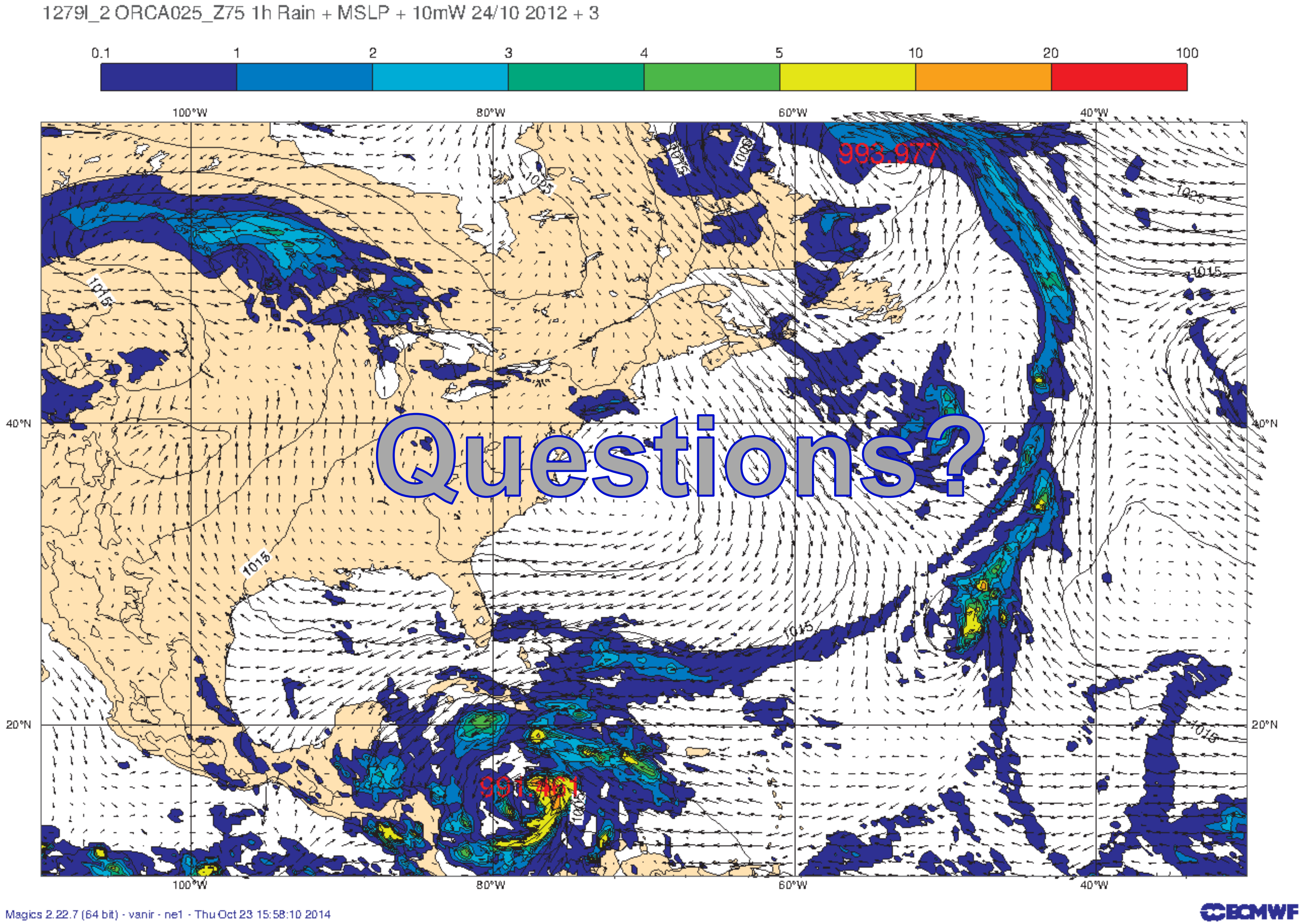
Questions?



1279l_2 ORCA025_Z75 1h Rain + MSLP + 10mW 24/10 2012 + 3
0.1 1 2 3 4 5 10 20 100
100°W 80°W 60°W 40°W
40°N 20°N
993.977
991.461
1015
1025
Magics 2.22.7 (64 bit) - vanir - ne1 - Thu Oct 23 15:58:10 2014
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