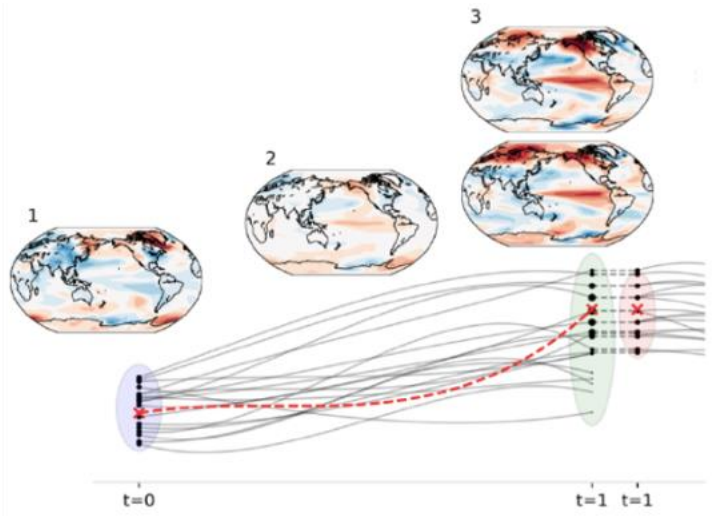

Ensemble simulations with IPSL model

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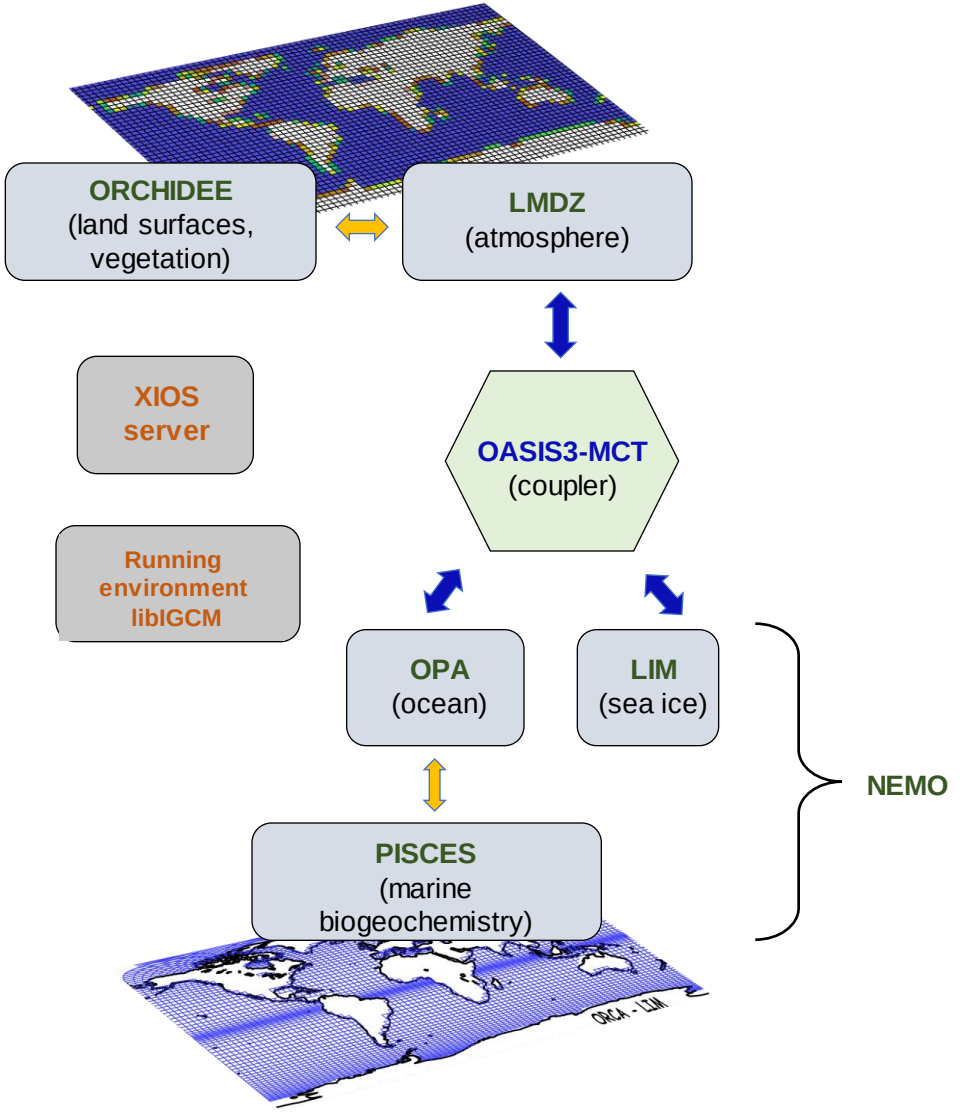
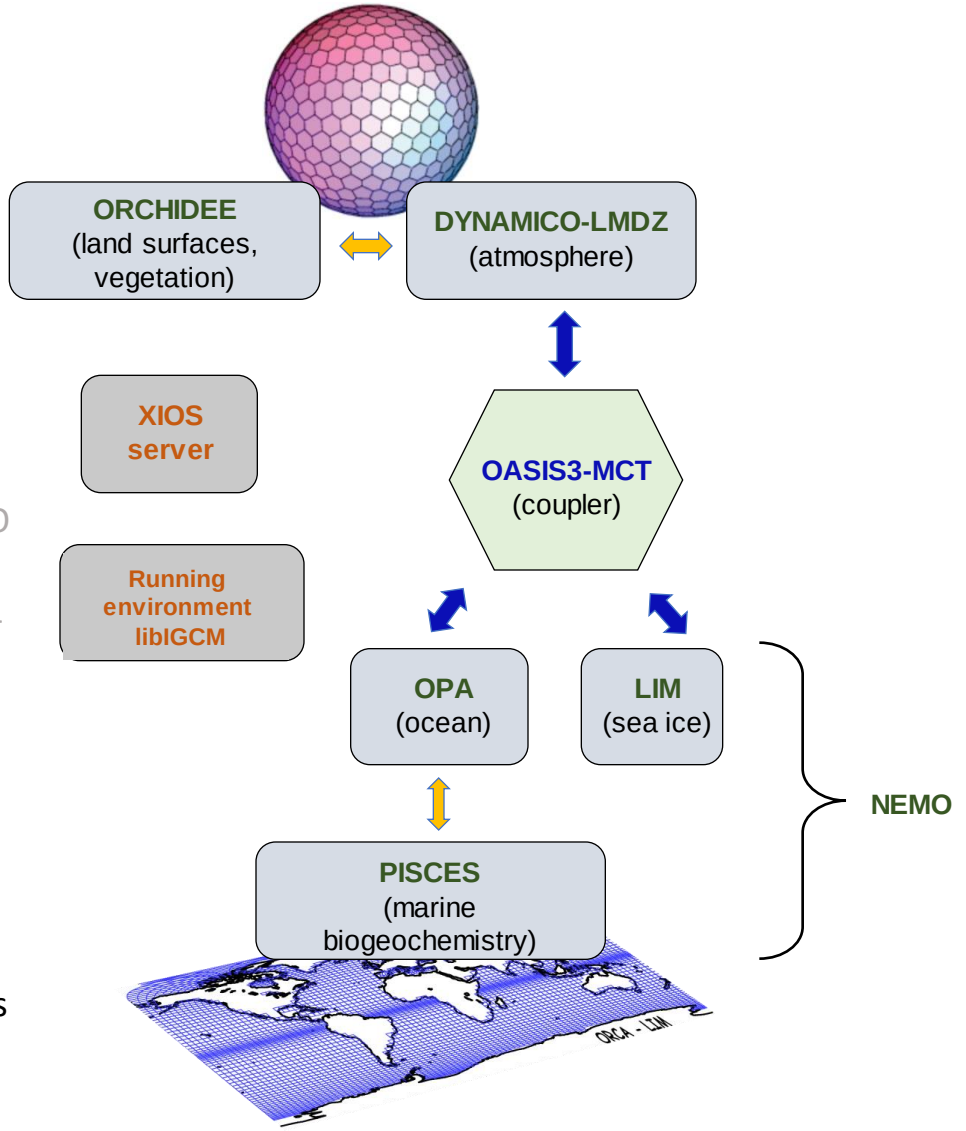
Context : IPSL-CM model

- **IPSL-CM6 (standard model)**
  - Components
    - LMDZ : Atmosphere, lon-lat grid
    - ORCHIDEE : Land surface, routing
    - NEMO version 3 : Ocean
    - LIM3 : Sea-ice
    - PISCES : Biogeochemistry
    - OASIS3-MCT : ocean-atmosphere coupler
    - XIOS version 2: Input/Output server
    - libIGCM : running environment
  - MPMD mode : LMDZ-ORCHIDEE, NEMO and XIOS server
  - Hybrid parallelization MPI-OpenMP for LMDZ-ORCHIDEE and MPI only for NEMO and XIOS server.
  - Participation in CMIP6 project with production of CMIP6 publication data ready files
  - Paleoclimate to future projections
  - Horizontal resolutions from 500 km to 50 km
  - Vertical resolution with 79 levels
  - Run on CPUs architecture (Intel and AMD computing cores)



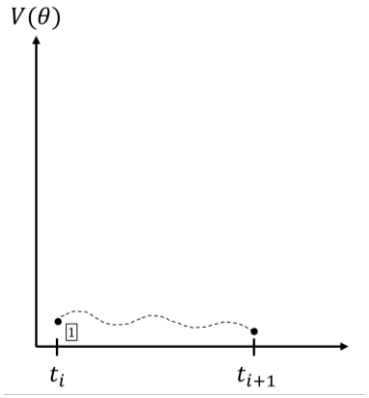
Context : IPSL-CM model

- **IPSL-CM7 (ongoing development)**
  - Components
    - **DYNAMICO-LMDZ : Atmosphere, icosaedral grid**
    - **ORCHIDEE : Land Surface, new routing model**
    - **NEMO version 4 : Ocean**
    - **SI3 : Sea-ice**
    - **PISCES : Biogeochemistry**
    - OASIS3-MCT : ocean-atmosphere coupler
    - XIOS version 2: Input/Output server
    - libIGCM : running environment
  - MPMD mode : DYNAMICO-LMDZ-ORCHIDEE, NEMO and XIOS server
  - Hybrid parallelization MPI-OpenMP for DYANMICO-LMDZ-ORCHIDEE and MPI only for NEMO and XIOS server.
  - Participation in CMIP6 HighResMIP project (atmosphere only) for 200 km to 25 km horizontal resolution
  - Scientific validation in progress at low resolution
  - Run on CPUs architecture (Intel and AMD computing cores). Work to target new architectures (GPUs) : DYNAMICO already done (based on OpenACC), LMDZ, ORCHIDEE, OPA : work in progress

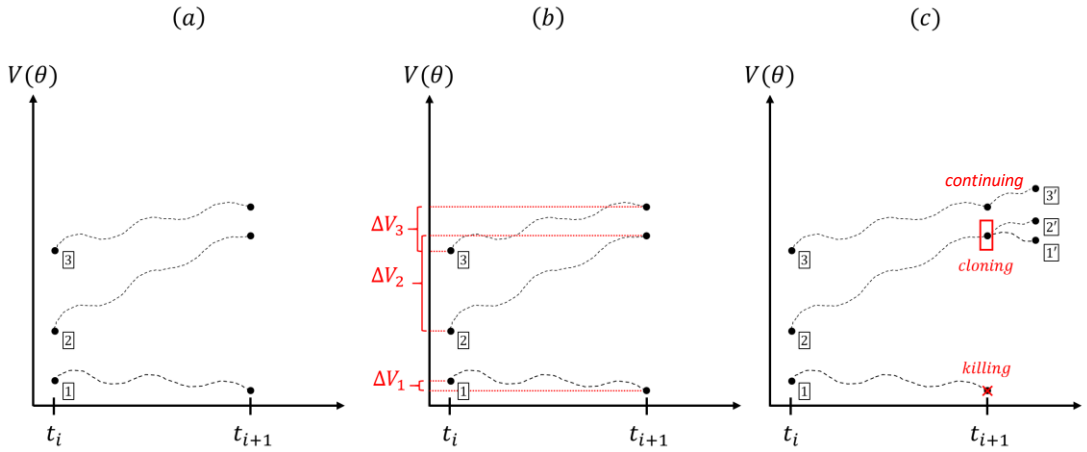


Context : Ensembles with IPSL model

- **Standard simulations :** 1 instance of the model over a period, one trajectory with regard to a given score function

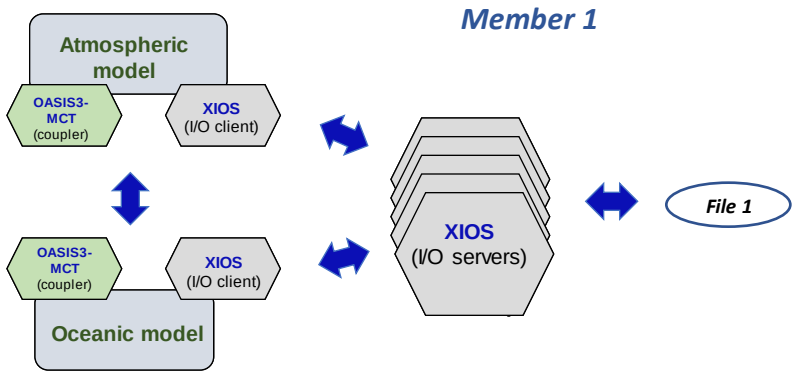


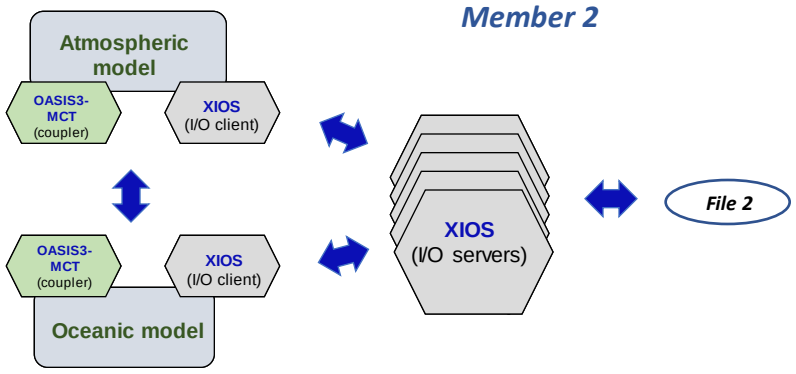
- **Ensemble simulations**
  - consist in running several instances/members in parallel and periodically selecting and cloning (with perturbation) trajectories which go in the favored direction (measured by a score function) and killing the other ones.
  - many possible protocoles with ensemble simulations to generate different members : **initial conditions**, parameters, forcing,…



Context : Ensembles with IPSL model

- **One instance vs many instances**
  - Each member of actual IPSL model produces its own output files. If the number of members is big (i.e > 10) :
    - A lot of inodes on computing centres filesystems : problem with strong constraints on quotas of inodes
    - A post-processing step is needed to “pack” output files to reduce inode footprint…
    - …but a post-processing step may be very loud (size of temporary buffer, computing ressources, time to solution)
  - Handling of perturbation of initial state : no existing automatic functionality to do that in the actual model
    - High risk to make errors with many members

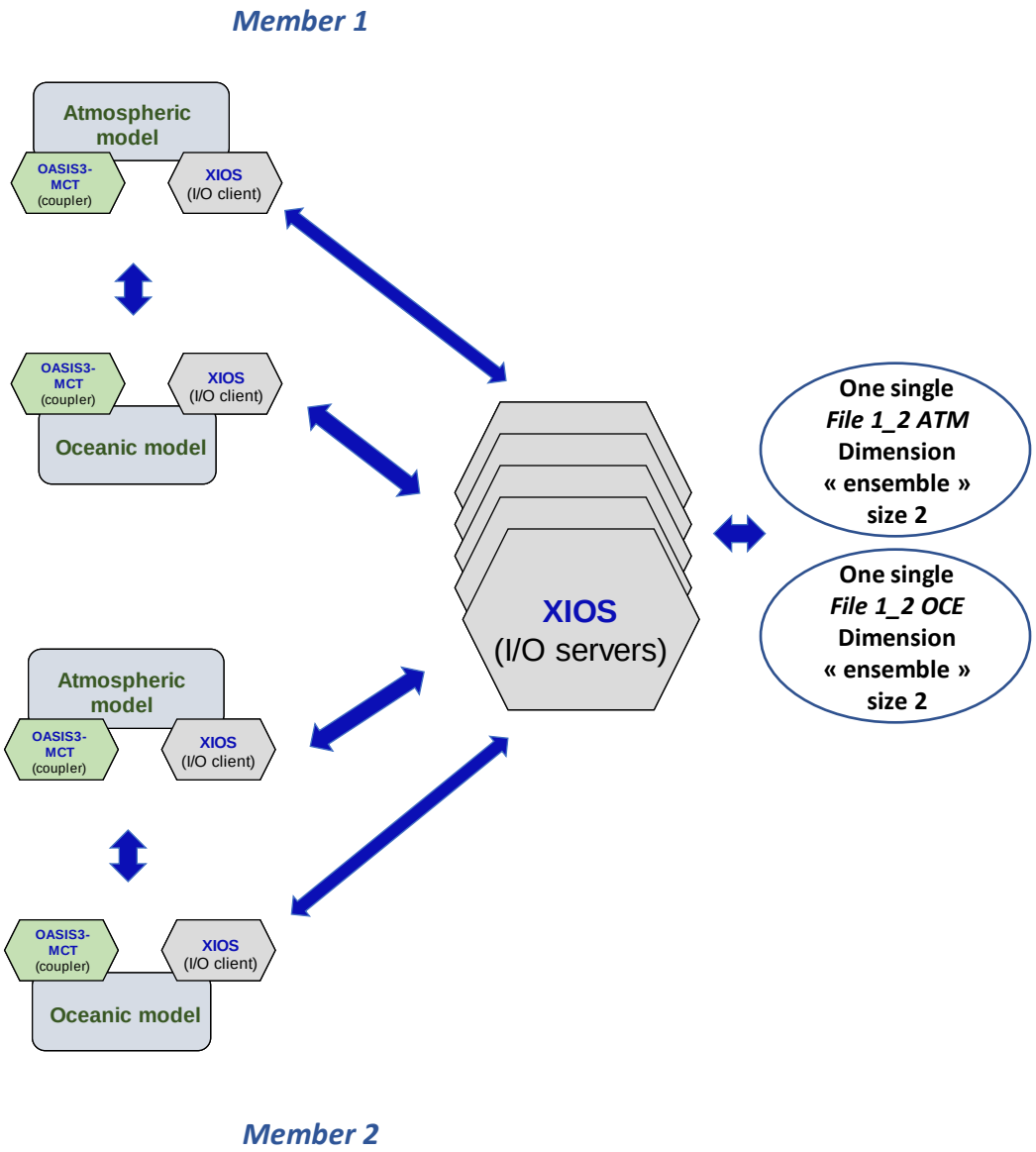




Development in IPSL model

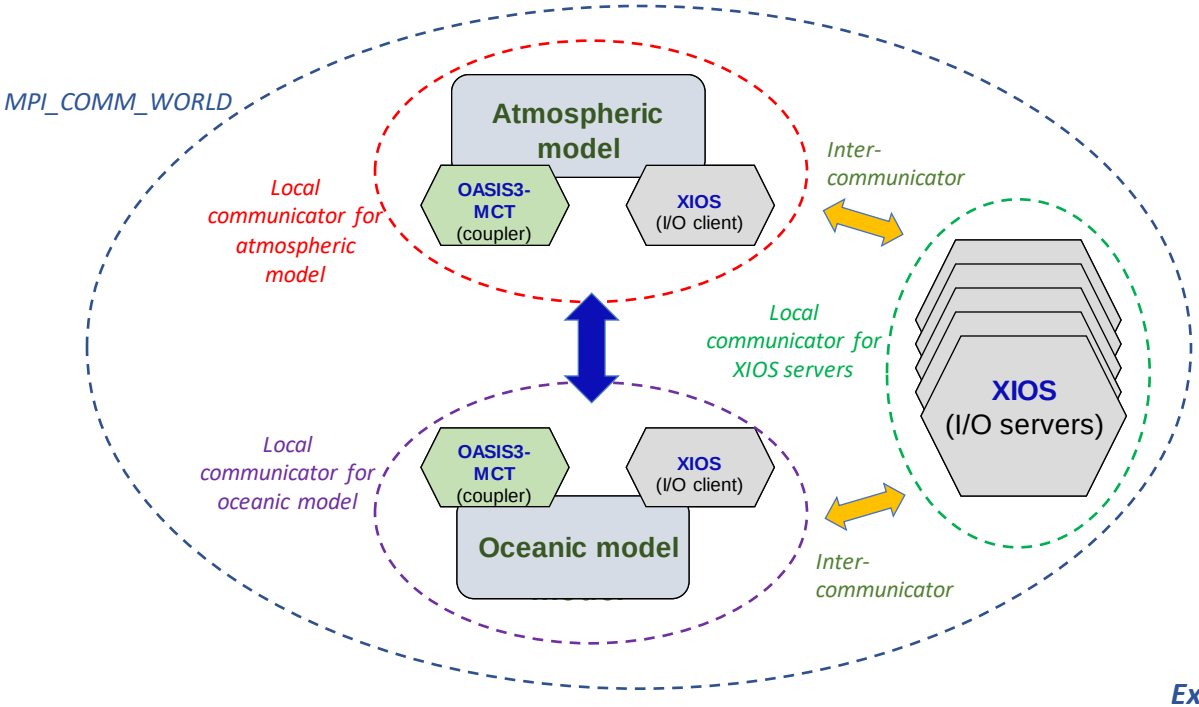
- **We have to adapt our model to be able to :**
  - Write out data from all members of a component into a single file (with ensemble dimension)
  - Synchronize all members after a given period
  - Use an external tool to determinate good/bad trajectories to extend with regard to scoring function
  - Automatically perturbate initial state if needed
  - Easily define the number of members, divided into pools by specifying the number of pools and the size of the pools in a parameter file

=> Modifications are needed in OASIS, XIOS, IPSL running environment (libIGCM)



Development in IPSL model

- **Ensemble management into XIOS and OASIS for single output file**
  - Communication between models, OASIS and XIOS
    - The handling of MPI communicators is done by OASIS in IPSL model.
    - MPI local communicators of the models are created by Oasis at initialization phase of the coupling to allow internal communication of the models.
    - MPI inter-communicators between XIOS and the models are created by Oasis at initialization phase to allow communication between XIOS and the models => this functionality is only available for 2 models/components.



Example with 1 member

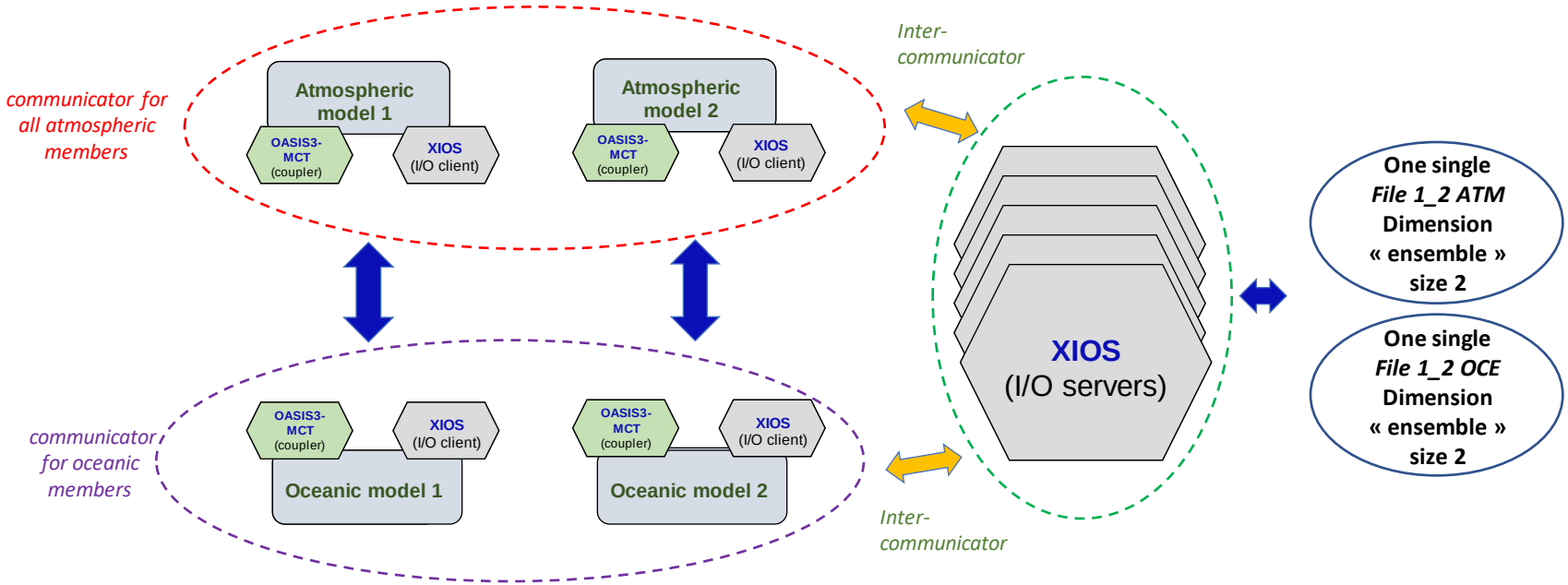
Development in IPSL model

Ensemble management into XIOS and OASIS

- Output data from all members of a component into one single file with ensemble dimension
  - Need that XIOS server communicate with all members of a component
  - Need to have a MPI communicator containing all members process of a component in order that the calls to XIOS subroutines are collective to all members of a component

=> Development of oasis_get_multi_intracomm and oasis_get_multi_intercomm by Oasis team in OASIS3-MCT_5.0

=> Development of a new dimension “ensemble” in XIOS, handled as an axis.

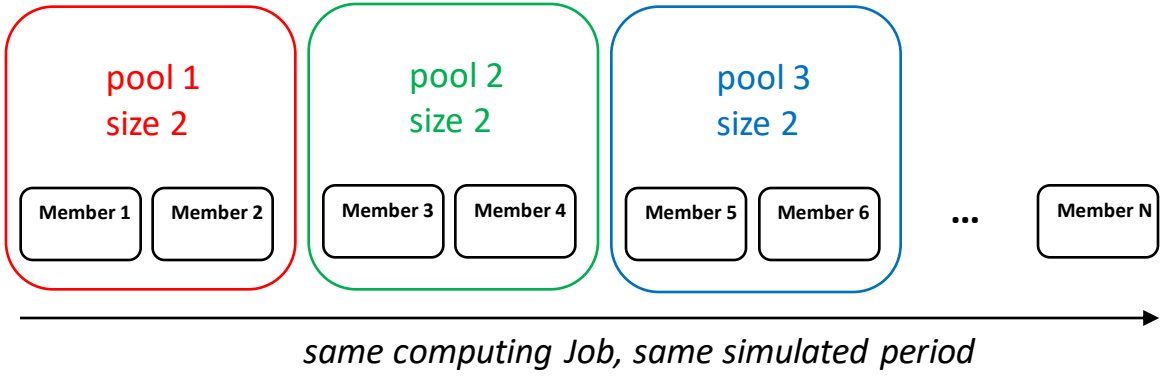


Example with 2 members

Development in IPSL model

- **Perturbation of initial state**
  - Fonctionality to perturbate starting state of LMDZ atmospheric model (dynamics part) based on a « white noise » on potential temperature on all points of the domain
  - Perturbation specific to one member (different perturbation between members)

- **Adaptation of IPSL running environment**
  - Management of execution of all instances of IPSL-CM model over a period in the same computing Job
  - Members are divided into pools. Use of ensembles parameters : number of pools, size of pool
  - The members of a pool run at the same time, the pools run sequentially one after the other, in the same Job on a given period.
  - Handling of restart files to allow the continuation or stop of a member
  - Use of external tool for the selection
  - Handling of perturbation to be applied (or not) to a specific member

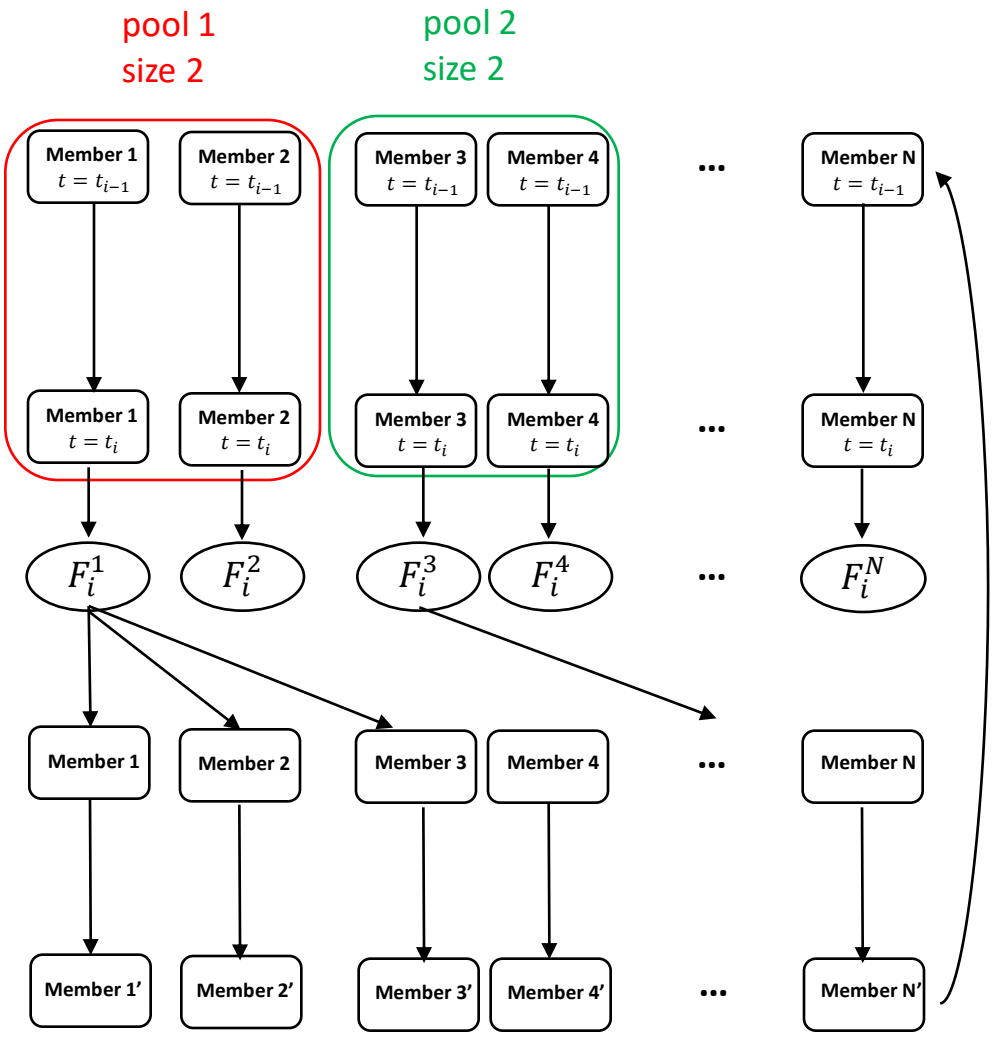


Development in IPSL model : ensembles workflow

1. Simulation of all members (pool after pool) over a period in the same computing Job

2. Selection of « good » members by computing a function score on output data

3. Perturbation based on « white noise » into initial state of the « new » members



Applications : Paleoclimatology

- **Reconstruction of 1500 years of paleoclimate (500 – 2014) (M. Khodri, IPSL)**
  - IPSL-CM very low resolution version : 200 km ocean, 400 km atmosphere
  - 1 instance/member run on ~800 AMD Rome computing cores at 48 SYPD
  - 80 members of IPSL-CM6 to run and synchronise after given period
  - Use of data assimilation methods (SIR-LIM-Analogues) to select after every simulated year
  - Output data aggregated on the fly by XIOS into one single file.
  - Results
    - 8 pools of 10 members on 8 421 cpu cores
    - Gain of a factor 80 for number of inodes
    - Time to solution for one pool does not depend of the size of the pool
    - Time to solution of all members is depending of the number of pools (and size of pools). Ex : 4h with 8 pools, 10 members per pool, ~6 SYPD
    - Additionnal cost in time to be taken into account between 2 periods : handling of restart, selection, perturbation,…depending on the size of the pool
    - One single file : very useful for analysis
    - Useful for low resolution that uses few cores : allows to apply for calls to benefit from computing hours (ex : PRACE) that are usually reserved for applications using several thousands cores.

Number of pools	Size of one pool	Nb cores	**Time to solution for 1 pool for 1 year period**	**SYPD for 1 pool**	**Time to solution for all members for 1 year period**	**SYPD for all members**
40	2	1 685	**30 min**	**48**	**20 h**	**1.2**
16	5	4 211	**30 min**	**48**	**8 h**	**3**
10	8	6 737	**30 min**	**48**	**5 h**	**4.8**
8	10	8 421	**30 min**	**48**	**4 h**	**6**

Applications : Present and extreme events

- **Reconstruction of last 130 years of historical period (1880 – 2014) (M. Khodri, IPSL)**
  - IPSL-CM low resolution version : 100 km ocean, 200 km atmosphere
  - 1 instance/member run on 1 800 AMD Rome computing cores (28 SYPD)
  - 80 members of IPSL-CM6 to run and synchronise after given period
  - Same data assimilation method and protocol of selection for previous case
  - Output data aggregated on the fly by XIOS into one single file
  - Results
    - 10 pools of 8 members on 15 360 cpu cores
    - Gain of a factor 80 for number of inodes
    - Time to solution for one pool does not depend of the size of the pool
    - Time to solution of all members is depending of the number of pools (and size of pools). Ex : 8h with 10 pools, 8 members per pool, ~3 SYPD

Number of pools	Size of one pool	Nb cores	**Time to solution for 1 pool for 1 year period**	**SYPD for 1 pool**	**Time to solution for all members for 1 year period**	**SYPD for all members**
40	2	3714	**50 min**	**28**	**33 h**	**0.7**
20	4	7927	**50 min**	**28**	**16 h**	**1.5**
16	5	9473	**50 min**	**28**	**13 h**	**1.8**
10	8	15360	**50 min**	**28**	**8 h**	**3**

- **Extreme events (heat waves) : on going work (R. Noyelle, IPSL)**
  - IPSL-CM atmosphere-only configuration : 200 km horizontal resolution.
  - Goal : simulate heat waves and therefore to select periodically the "best" trajectories that can cause heat waves
  - Between 100 and 1000 members with selection every 4-5 simulated days

Conclusions - Perspectives

- Nice and effective example of collaboration between tools (and teams) : OASIS and XIOS
- The contract has been fullfilled : no impact on the inodes created for output files when running ensembles…
- Very useful (especially for low resolution) to target allocations reserved for many thousands computing cores
- What about operations/reductions between members ?
  - Functionality to allow reductions between members with XIOS has been already developped by NCAS Reading (but no output in one single file)
  - Actual version of IPSL model : possible to do some reductions/operations between members but only between members of a pool (and not between all members).
  - Reductions/operations between members could have an impact on the time to solution because they are performed on model/client side (synchronization of all members)
  - Modifications were needed into the components to handle ensemble parameters (number of pools, size of pool). Better to be less invasive in the components.
  - Ideal would be to have asynchroneous services in XIOS dedicated to such operations/reductions between different members
    - Not yet available but possible in new XIOS version : XIOS3 (see Yann Meurdesoif's talk tomorrow)

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Thank you !