Project Hermès: High-Resolution Modeling of the Earth System

MOPGA mi-parcours

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Questions: metamodels and supermodels (from kickoff, February 2019)

- Supermodels: some components replaced by learning agents.
- Metamodels: low-dimensional emulators, “fast approximate models”.
- Fundamental questions still unanswered:
  - Are model-free methods useful?
  - How do we derive the invariant basis of a complex system?
  - Can we use ML to derive the functional form of a slow manifold?
  - Can we derive a useful model hierarchy?
  - Can this metamodel be used for parameter uncertainty exploration?
  - How much physical knowledge (e.g conservation laws) must be embedded in the ML? What if the embedded knowledge is incorrect? (“*It’s not what you don’t know, it’s what you know for sure that just ain’t so*”, Mark Twain never said.)
  - What happens to supermodels as the features of the training data evolve?

Project Hermès: Strategy (from kickoff)

- Project Hermès will study learning methods for metamodels and supermodels, for atmosphere and ocean, across a hierarchy of models (e.g 1D and 3D, idealized, LES, GCM, ...)
- Project Hermès will aim to foster collaboration in the emerging field of Climate/ML: between the ML and climate communities, theoretical and applied science, between institutions in EU/US/...
- Project Hermès will aim to build a community of interdiscplinary scientists equally at home in machine learning and Earth System science.
- Project Hermès will aim to be open-minded and opportunistic: this is a nascent field and there will be unexpected twists and turns!
- All work will be shared with the community via articles in open-access journals, open-source software, open data. No commercial or proprietary interests. Articles will list LSCE affiliation first and acknowledge MOPGA funding.

Collaborations beginning under Project Hermès (from kickoff)

Initial presentations:

- Presentation of the ML challenge to the community: IPSL (Dec 2018), LSCE (Jan 2019).

Beginning collaborations:

- Extension of Bolton-Zanna approach using high-resolution ocean models
  - In collaboration with LOCEAN, Uni Grenoble, Oxford, Princeton
  - MOPGA postdoc (LSCE) under recruitment. Anna Sommer, see Improved representation of ocean mesoscale turbulence using Machine Learning
- Application of ML to model calibration
  - In collaboration with LMD, Univ Exeter, École Normale Supérieure, ANR High Tunes project.
  - Doctoral student (ENS) under recruitment. Student decided to go to industry!
  - Recruited postdoc Redouane Lguensat: see project Earth System Model Calibration using Machine Learning
- Detection of features (e.g tropical cyclones) in high-resolution climate data.
  - In collaboration with IPSL.

Proposed timeline (from kickoff)

- Year 1:
  - Recruitment for subprojects (see above).
  - Monthly Journal Club starting Feb 2019. Active as AI4Climate Journal Club
  - Presentation of the Climate/ML challenge to the community: IPSL (Dec 2018), LSCE (Jan 2019), SAMA IA-Climat (Feb 2019).
  - Invited presentation at LEFE/MANU Journée Thematique à Rennes (Feb 2019)
  - Invited keynote presentation at EGU Assembly Vienna (April 2019).
  - Articles in preparation:
    - *Metamodels and supermodels*: ideas and challenges from machine learning in Earth System Science. Published in *Phil. Trans.* as Climbing down Charney's ladder.
    - *The biology analogy*: will *in silico* science become like *in vitro*? In progress
    - « Science des données » versus science physique : la technologie des données nous conduit-elle vers une nouvelle synthèse ? published in Comptes Rendus Géosciences.
- Year 3:
  - Demonstration of supermodeling approach in at least one aspect of IPSL model.
  - Demonstration of ML application in calibration of IPSL model.
- Year 5:
  - Hybrid (ML/physics-based) model in production.

Progress since kickoff: projects

- Improved representation of ocean mesoscale turbulence using Machine Learning
  - Representing the role of mesoscale eddies (10-300 km) in IPCC-class ocean models.
  - Led by Anna Sommer, UEA (former MOPGA postdoc). See presentation to follow.
  - Oral presentation at AGU 2019.
- Earth System Model Calibration using Machine Learning
  - Fundamental understanding of calibration of the coupled ocean-atmosphere system.
  - Led by Redouane Lguensat, MOPGA postdoc. See presentation to follow.
  - Poster presentation at AGU 2020, ECMWF-ESA Workshop on Machine Learning
- Revealing changes in global ocean circulation under global heating using machine learning (new since kickoff!)
  - Identifying interpretable dynamical ocean regimes in CMIP models. Based on Sonnewald et al. 2019, this will enable us to study changes in fundamental ocean circulation under climate change.
  - Collaboration between Redouane Lguensat and Maike Sonnewald, Associate Research Scholar, Princeton University. See presentation to follow.
  - Poster presentation at AGU 2020, Climate Informatics 2020
  - Manuscript under review at *PNAS*

Progress since kickoff: articles, presentations, outreach

- Articles:
  - Climbing down Charney's ladder: : Machine Learning and the post-Dennard era of computational climate science, *Phil. Trans. 2020*
  - « Science des données » versus science physique : la technologie des données nous conduit-elle vers une nouvelle synthèse ? Comptes Rendus Géosciences 2020.
- Presentations:
  - *On the importance of tuning ocean configurations for climate simulations*, 18 January 2021, DRAKKAR workshop, Grenoble.
  - *Challenges raised by global ocean configurations in the context of climate modelling*, 31 January 2020, COMMODORE workshop, Hamburg.
  - *Évolution des technologies des données et de calcul : opportunités et défis pour la simulation et l'analyse du système Terre*, 28 January 2020, Académie des Sciences, Paris
    Invited talk at the Académie des Sciences in Paris, in the colloquium *Face au changement climatique, le champ des possibles*.
  - *Reconstruction of Sub-grid-scale Buoyancy Fluxes from Large-Scale ocean Variables*, 12 December 2019, San Francisco: oral presentation at AGU Fall Meeting 2019.

Progress since kickoff: articles, presentations, outreach

- Presentations (continued):
  - *Machine Learning and the Post-Dennard Era of Climate Simulation*, 02 September 2019, Corpus Christi College, Oxford
    Invited talk at the *Workshop on Machine Learning for Weather and Climate Modelling*
  - *Scientific and computational challenges in understanding climate change*, 21 August 2019, IIT Madras, India:
    Dr R Pitchai Endowment Lecture, Indian Institute of Technology, Madras
  - *Metamodels and Supermodels: Ideas and challenges from Machine Learning for Earth System Science*, 15 May 2019: Smagorinsky Room, GFDL, Princeton
    An overview of machine learning approaches in Earth system modeling.
  - *Machine Learning and the Post-Dennard Era of Climate Simulation*, 04 May 2019, Reading UK
    Invited lecture at the European Centre for Medium-Range Weather Forecasting.
  - *Trends in data technology: opportunities and challenges for Earth system simulation and analysis*, 03 May 2019, Reading UK
    Invited lecture at the European Centre for Medium-Range Weather Forecasting.

Progress since kickoff: articles, presentations, outreach

- Presentations (continued):
  - *Modeling Systems in the post-Dennard era*, 11 April 2019, EGU 2019, Vienna
    Keynote presentation, EGU AS1.5/CL5.05/ESSI1.2/NP1.4/OS4.20.
  - *Trends in data technology: opportunities and challenges for Earth system simulation and analysis,* 25 March 2019, Barcelona
    Invited lecture at WGCM CMIP Workshop.
  - *Lessons from the WIP and Vision for the Future*, 10 January 2019, Sorbonne Université, Paris
    An overview of 5 years of activity of the WGCM Infrastructure Panel.
  - *Project Hermès: Machine Learning and High-Resolution Modeling of the Earth System*, 06 November 2018, CNRS, Paris
    Invited lecture at the 42nd ORAP Forum, *AI for HPC and HPC for AI*

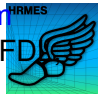
Progress since kickoff: articles, presentations, outreach

- Outreach:
  - EGU 2021 session *Machine learning for Earth system modelling*, Lguensat, co-convenor.
  - EGU 2020 session *Machine learning for Earth system modelling*, Lguensat, co-convenor.
  - AGU 2020 session *Innovation and Exploration in Observed and Model Oceanographic Data Using Interpretable Machine Learning*: Balaji and Lguensat, co-convenors.
  - 2h talk for the AI-HPC Master of Centrale Marseille, "AI and numerical modeling", by Lguensat.
  - IPSL EUR climate School funding for a M2 internship
  - Climate Informatics Workshop Hackathon 2020, Lguensat, organizer.
  - Climate Informatics Workshop Hackathon 2019, Sommer, organizer.

Project website: https://hrmes-mopga.github.io/

Allied projects

- High Tune: HIGH resolution simulations to improve and TUNE the boundary-layer cloud parameterizations: IPSL, CNRM, U. Exeter. ANR Grant.
- QUEST: Quantifying Uncertainties and Enhancing the Speed of climate model Tuning. IPSL, LSCE. PRACE award.
- ESPRI-IA: ESPRI-IA accueille l'ensemble des collègues qui souhaitent participer à l'animation de la communauté de l'IA de la fédération de laboratoires IPSL. Part of Mésocentre ESPRI.
- eNATL60: tide-resolving, submesoscale permitting, basin scale ocean simulations in preparation for SWOT satellite mission, Grenoble, Ocean Next. PRACE award.
- AI4Climate: pluridisciplinary research group at Sorbonne University seeking synergy between Climate and Environmental sciences and Data Science. Now co-sponsors our Journal Club.
- (newly funded) M^2LInES: Multiscale Machine Learning In coupled Earth System Modeling: International collaborative project (New York University, Princeton, GFDL, Columbia, LDEO, NCAR, MIT, CNRS-IGE, and CNRS-IPSL).



Proposed timeline (from kickoff): still on course!

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Summary

- Project Hermès is still on track, with some twists and turns
- We have maintained a good working environment despite the pandemic, thanks in particular to strong commitment from the host institution!
- Still maintaining commitment to high resolution, coupled modeling, collaboration, developing an interdisciplinary community (see strategy slide)
- Principal collaborators: Julie Deshayes, Olivier Boucher, Frédéric Hourdin, Julien le Sommer, Aurélie Albert.
- Hosts: Philippe Bousquet (LSCE), Robert Vautard (IPSL).
- Administration: Isabelle Rault, Florence Gerry, Catherine Huguen, Marie Pinhas, Alexandra Rubert, Mina Melloulchi