Régionalisation des effets des changements climatiques sur les ERV à La Réunion et dans le SOOI

Regionalization of the impacts of climate change on VRE in Reunion and in the SWIO

Béatrice Morel

HyLES Workshop – nov. 2024

Outline

- Introduction
- VRE assessment at ENERGY-Lab
- Why and how we downscale
- Applications
  - BRIO project
  - SWIO-Energy project
- Conclusion

Introduction

From the **Agenda 2030** … to the … ear E… ram (PPE) for Reunion

Translating ***global*** *objectives into so… ailore… eds and specificities*

GLOBAL SCALE: AGENDA 2030

fig. 1. **Share** of electricity production from RE (1985-2023)
Ritchie and Rosado 2020

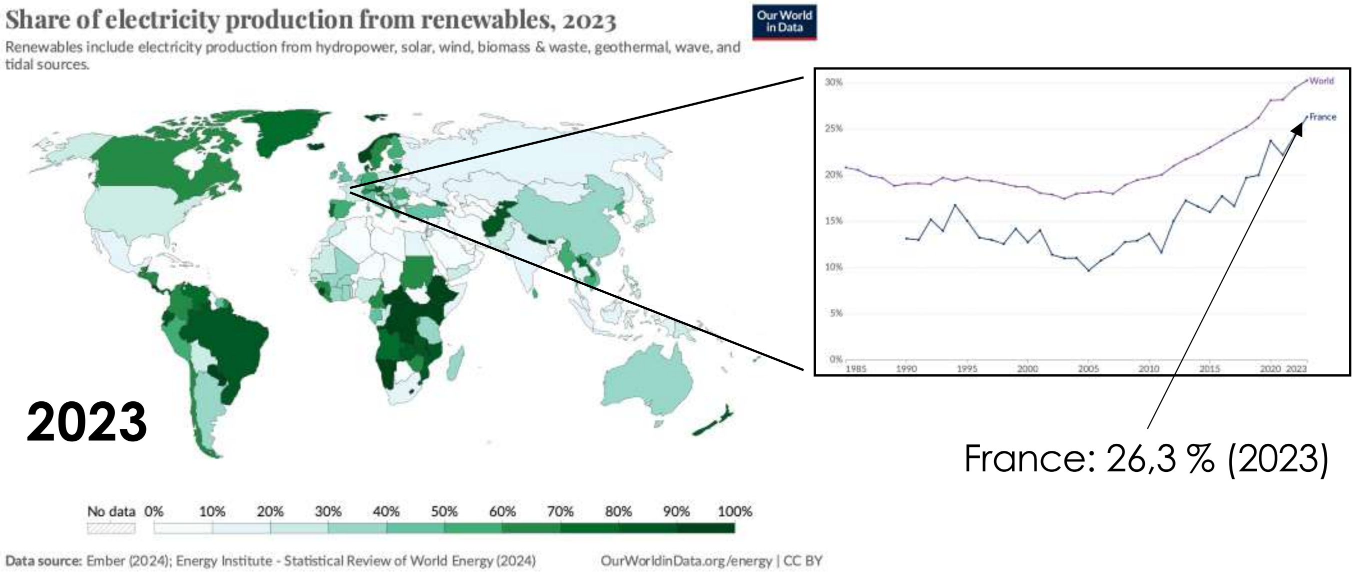
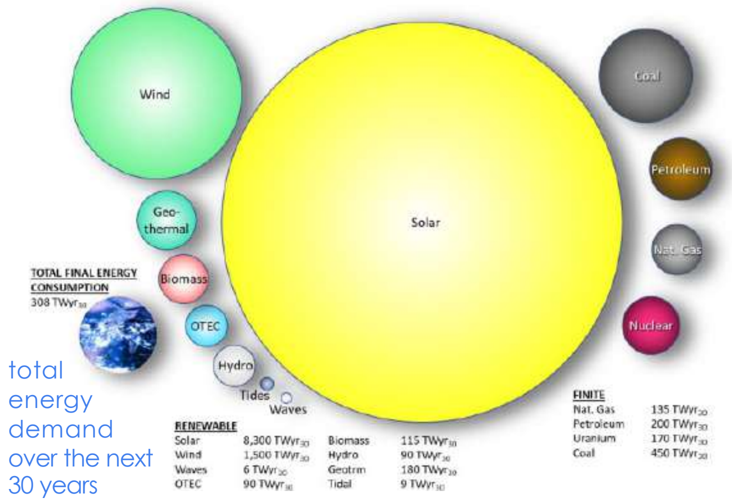


fig. 2. **Reserves** in renewable and finite energy sources over the next 30 years – *Perez and Perez 2022*



Introduction

From the **Agenda 2030** … to the Multi-Year Energy Program (**PPE**) for Reunion

*Translating **global** objectives into solutions tailored to **local** needs and specificities*

GLOBAL SCALE: AGENDA 2030

LOCAL SCALE: PPE REUNION

tab. 1. **Targets** for Solar PV and Wind energy by 2028

Energy sector	Installed capacity in 2023	Objectives by 2028	Target capacity
Solar PV	266,2 MW	+310 MW vs. 2018	440-500 MW
Onshore wind	19,8 MW (Ste-Suzanne) *+10 MW (Ste-Rose – 2025)*	+75 MW vs. 2016	91,5 MW
Offshore wind	N/A	Dev. of 40 MW	40 MW

REUNION

French overseas territory

2512 km^2

885 700 inhab. (1/1/2024)

- **Non-Interconnected Zone**
- **Electricity production in 2023**

  3 085,1 GWh – **56,6 % from RE**

  Conversion from coal to biomass
- **Heavy dependence on imported energy (88,6 % in 2023)**

  Imported biomass
- **Self-sufficiency goal**

  By **2030**: achieving 100 % RE electricity

  *Increase **Solar PV energy by ~2***

  *Expand **Wind energy by a factor of ~4***

Introduction

Towards a Sustainable Energy Transition in Reunion: Opportunities and Challenges

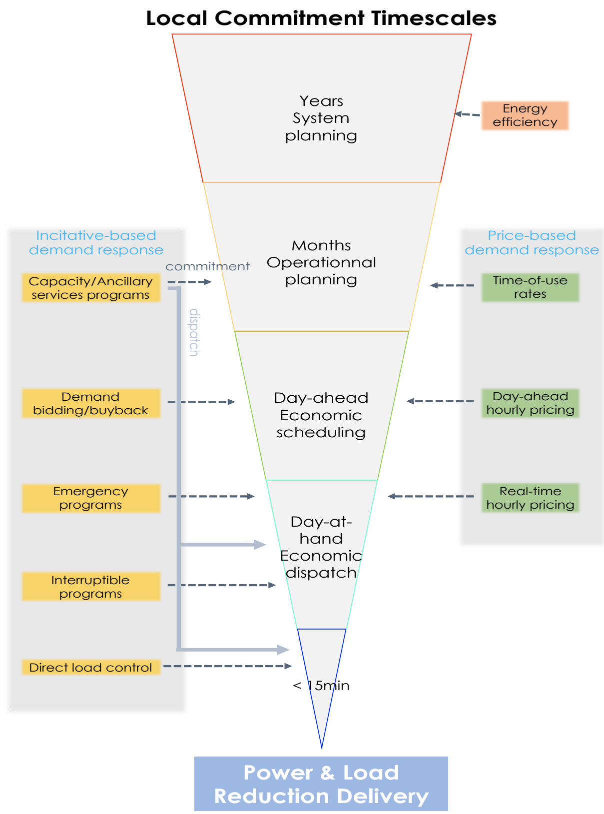
Category	Key opportunities	Key challenges
🌍 **Geographical**	Reduce energy dependency on fossil fuels	Limited space and **local resource** constraints
⚡ **Production & grid**	Diversify mix (**solar, wind**, biomass, **G-H2**)	**Variability of renewables**, grid infrastructure
Green hydrogen (G-H2)	Long-term storage, reduce emissions	High production costs, renewable hydrogen
Demand management	Enhance flexibility	Lack of smart grid technologies
Environment & society	Reduce emissions, environmental benefits	Social acceptance of renewables
Innovation	R&D in microgrids, innovative storage	High cost of pilot projects
Governance	Achieve autonomy targets by 2030	Stakeholder coordination

Introduction

Scientific Challenge: Characterizing and Predicting **Variability** in VRE Resources

PROBLEMATIC

fig. 3a. **Timescales** of demand response programs



adapted from DREAM-GO Report 2018

Introduction

Scientific Challenge: Characterizing and Predicting **Variability** in VRE Resources

PROBLEMATIC

fig. 4. **GHI** @ Moufia (RUN **BSRN** station)

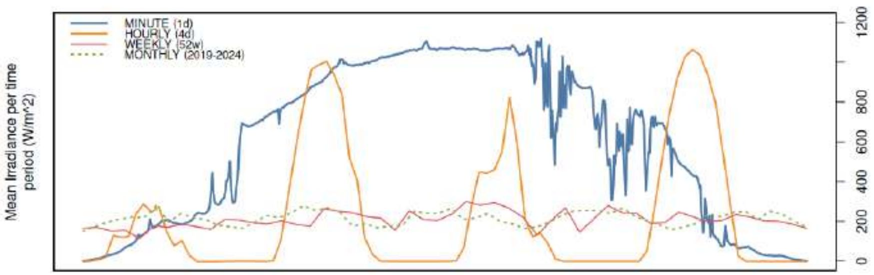


fig. 5. **Wind speed** @ 10 m (left – *Uwajeneza et al. 2023* ***SASEC***) and @100 m (right – *Global Wind Atlas*) over Reunion

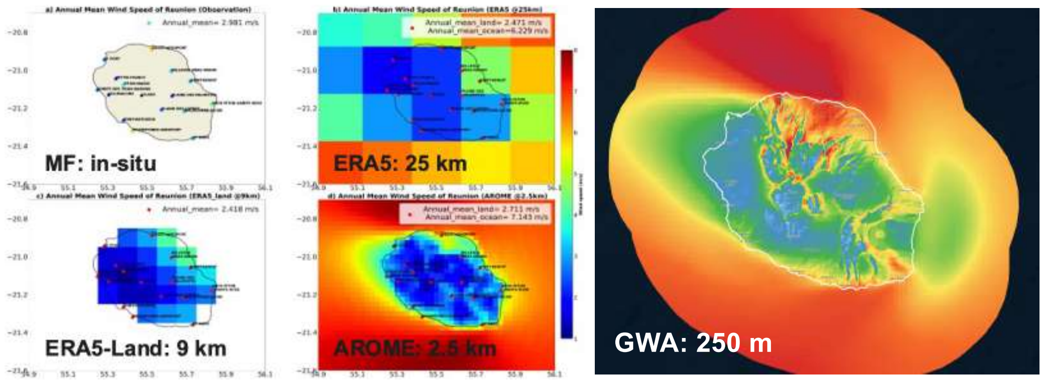
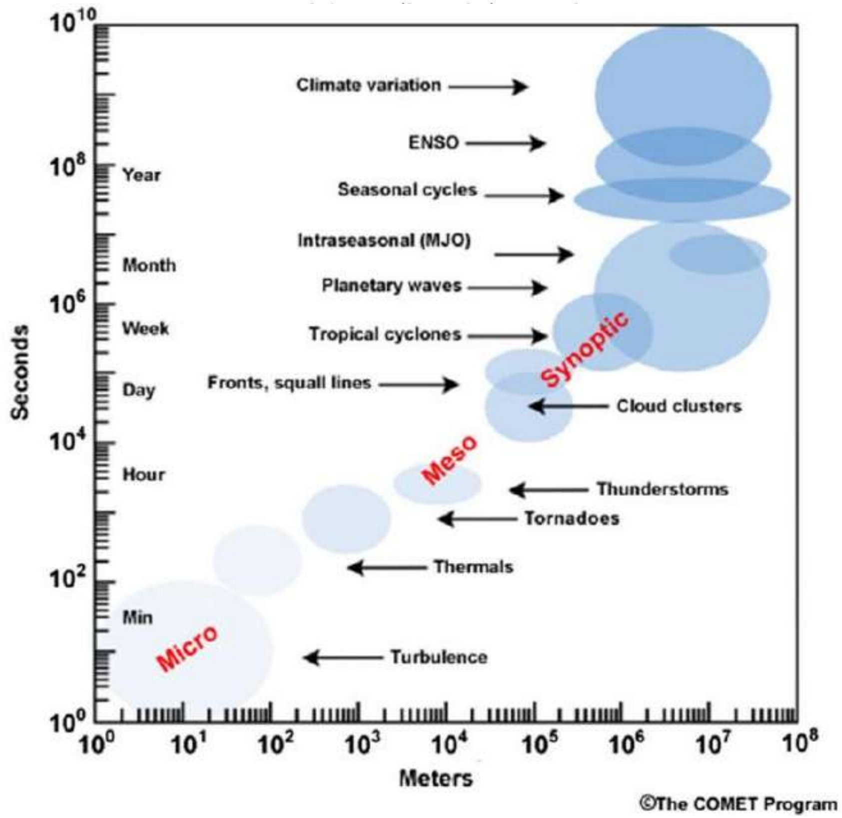


fig. 3b. **Timescales** of climate variability



Introduction

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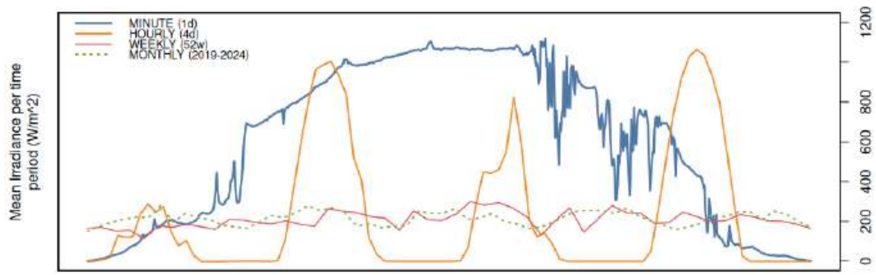

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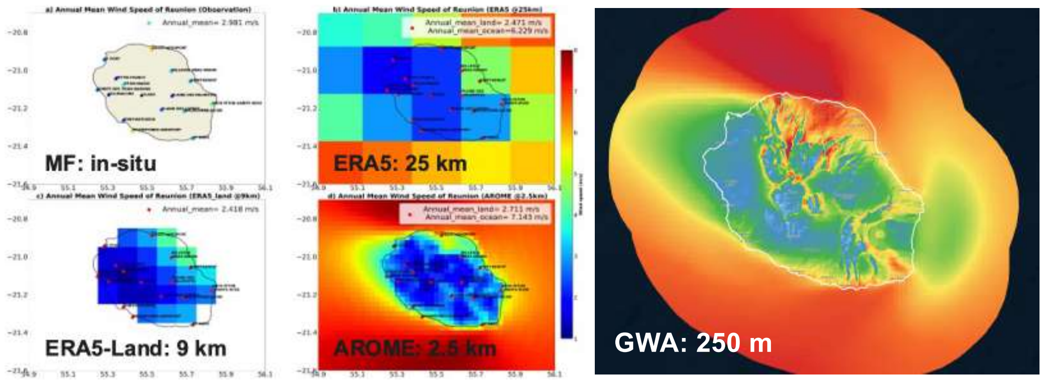


SCIENTIFIC QUESTION

How can we accurately characterize and predict spatial and temporal variability in VRE resources at fine resolutions to optimize their integration into energy systems?

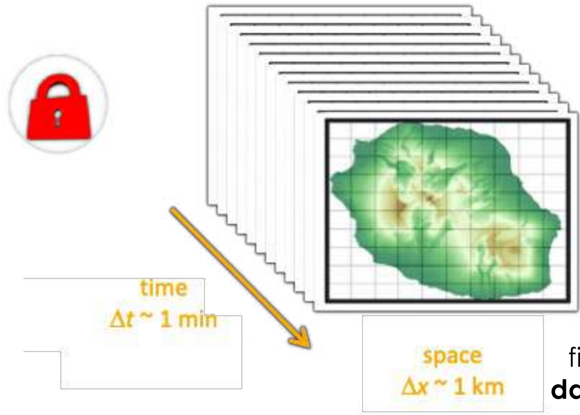


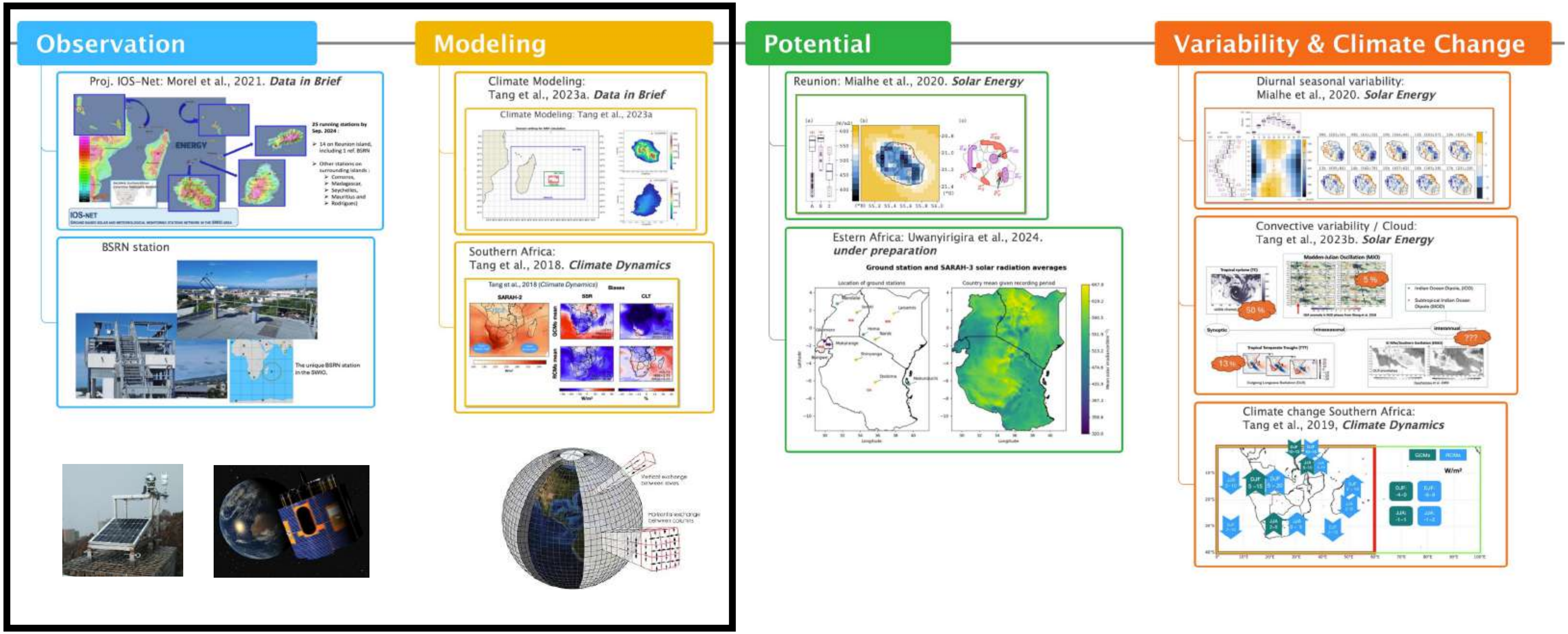
fig. 6. Needs in **HR data** to characterize spatial and temporal variability

VRE assessment at ENERGY-Lab

Spatial and Temporal Variability of VRE

Solar

fig. 7. **Framework** for solar resource assessment at ENERGY-Lab



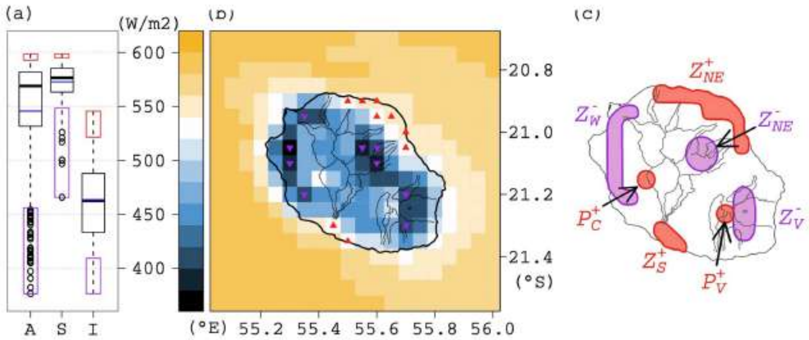
VRE assessment at ENERGY-Lab

Spatial and Temporal Variability of VRE

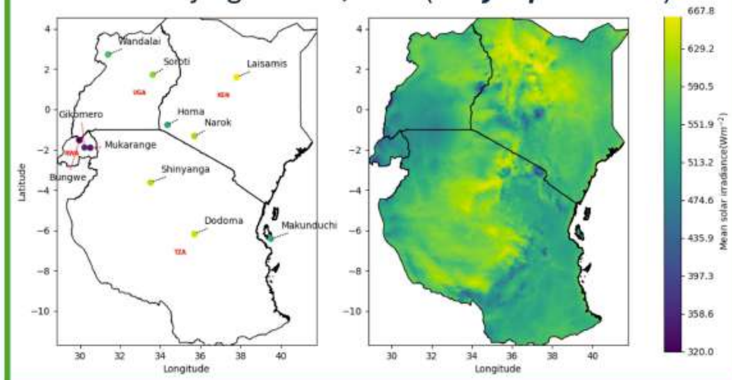
Solar

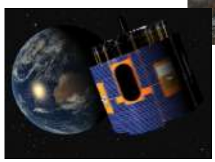
Observation — Modeling — **Potential** — Variability & Climate Change

Mialhe et al., 2020 (***Solar Energy***)



Uwanyirigira et al., 2024 (***not yet published***)





VRE assessment at ENERGY-Lab

Spatial and Temporal Variability of VRE

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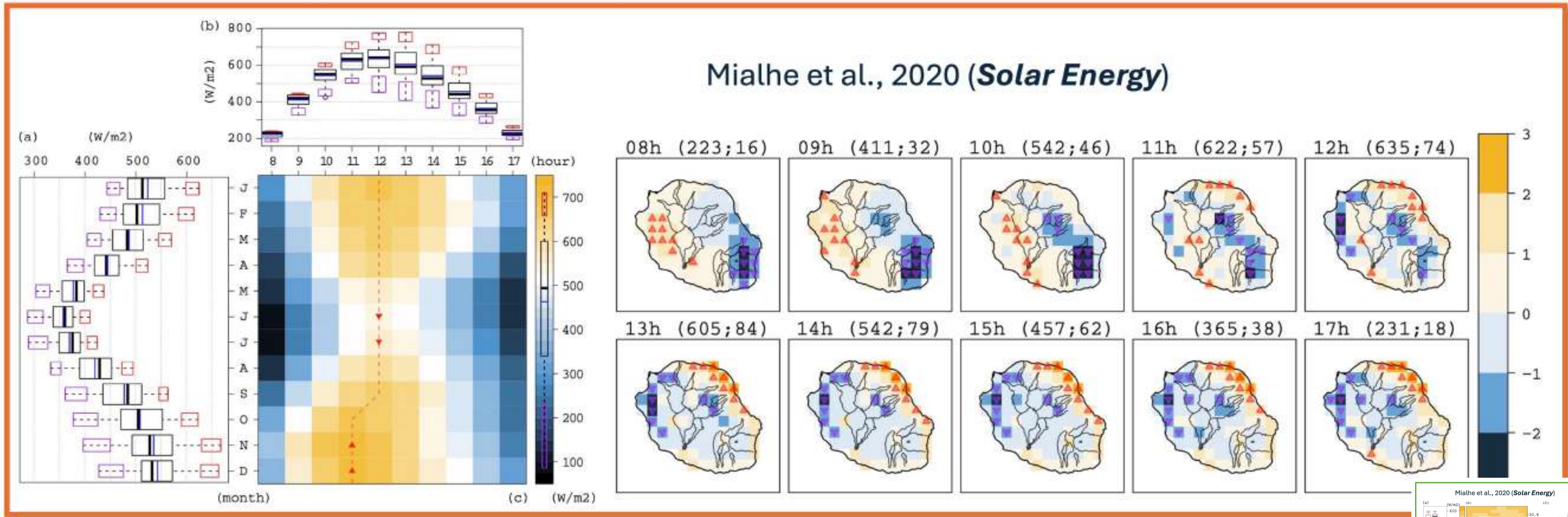
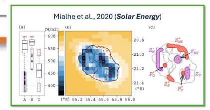
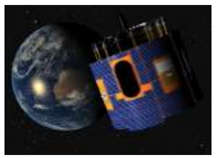
Observation — Modeling — Potential — **Variability & Climate Change**







VRE assessment at ENERGY-Lab

Spatial and Temporal Variability of VRE

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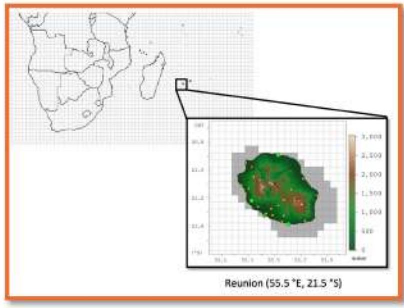

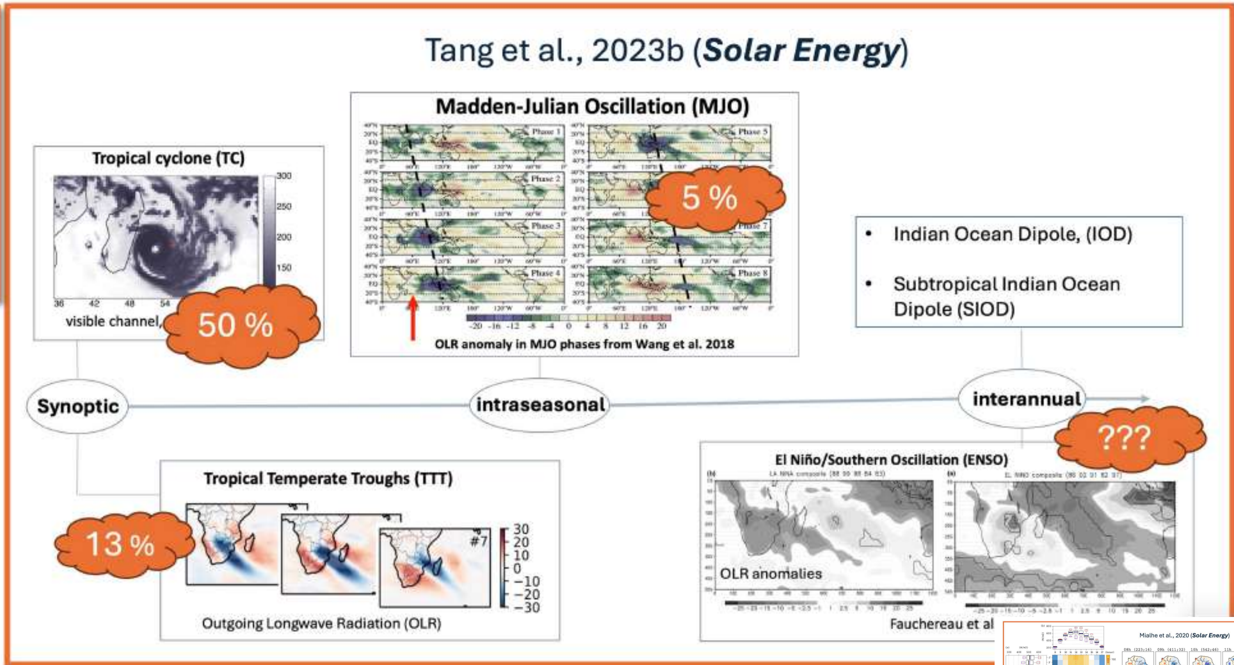

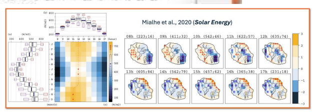

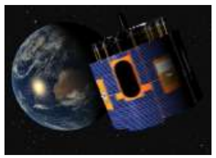

VRE assessment at ENERGY-Lab

Spatial and Temporal Variability of VRE

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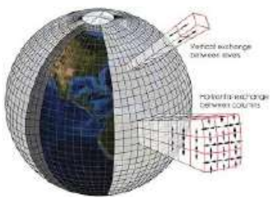
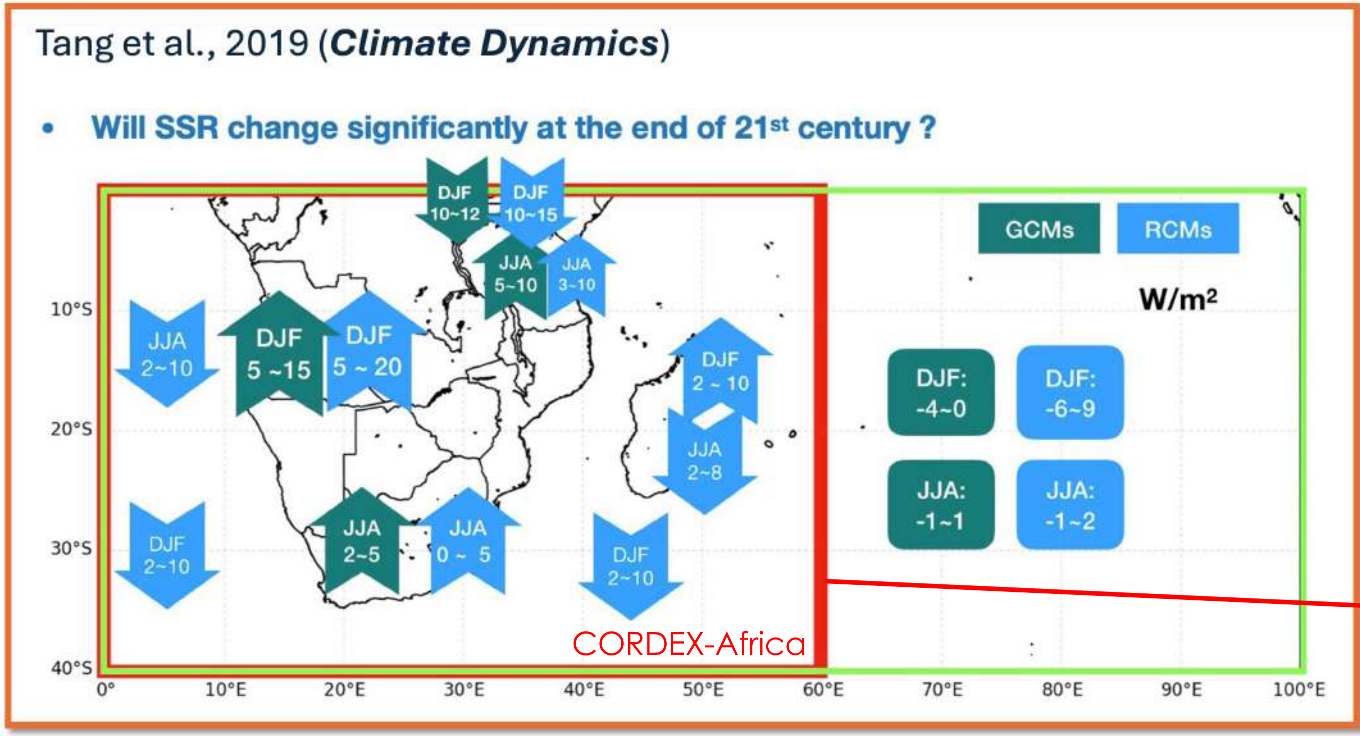
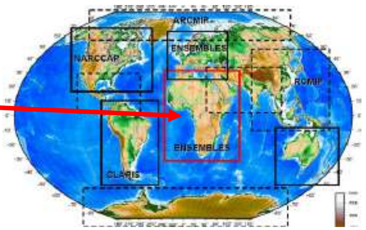






VRE assessment at ENERGY-Lab

Spatial and Temporal Variability of VRE
Solar & Wind

tab. 2. **Comparison** of data sources: advantages and limitations

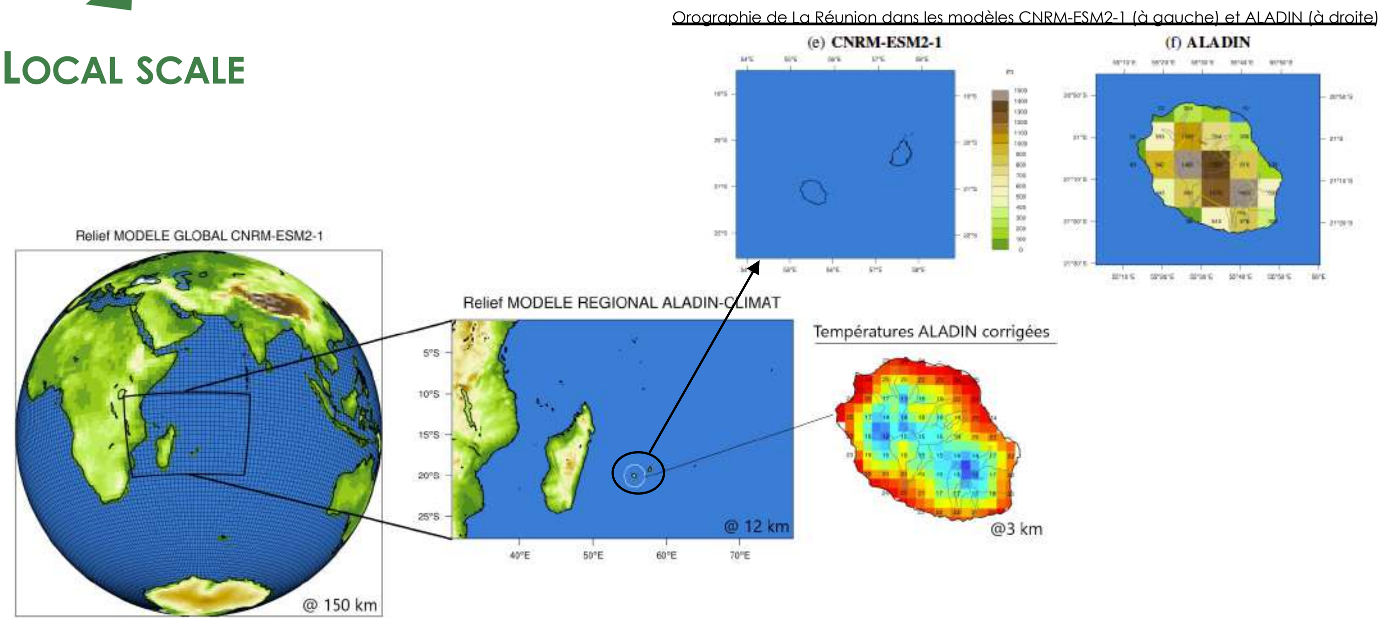
Data source	Weather station	Satellite	Climate model Climate reanalysis
Advantage(s)	• Very precise data for specific locations • Fine temporal resolution (e.g., minute, hourly) • Captures local effects such as terrain roughness or natural barriers • Allows validation of gridded data (e.g., climate models, satellite products)	• Good spatial coverage, including remote or maritime zones • Available over long periods and globally consistent • Provides large-scale climate trends and enables validation of climate models	• Global models provide large-scale climate trends • Regional models enable **downscaling** to fine resolutions (1-10 km), critical for complex areas • Reanalyses offer consistent time series over several decades with hourly data
Limitation(s)	• Limited spatial coverage, especially in remote areas • High costs for installing and maintaining additional stations	• Limited spatial resolution (typically 10-30 km) • Less precise in complex areas like islands or mountainous regions	• Regional models require significant computational resources for **downscaling** • Potential biases transmitted from global to regional models

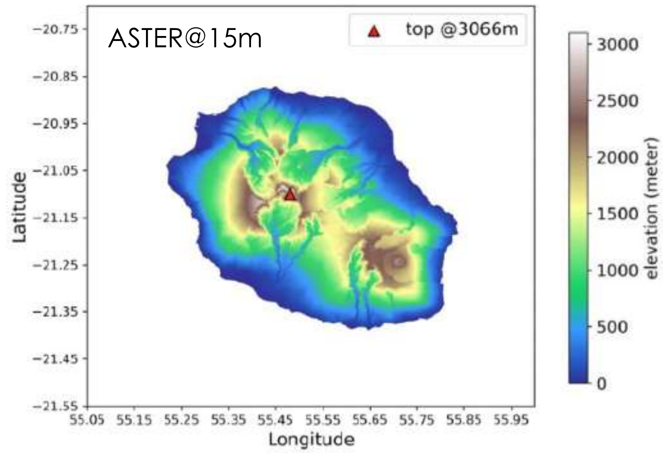
Why and how we downscale

GLOBAL SCALE

Downscaling: a technique that facilitates **regionalizing** weather/climate information to a **local scale** by utilizing data from a broader, **large-scale** context

LOCAL SCALE





Tang et al. 2023

fig. 8. **Steps** of the downscaling procedure in the BRIO project
Leroux et al. 2024

Why and how we downscale

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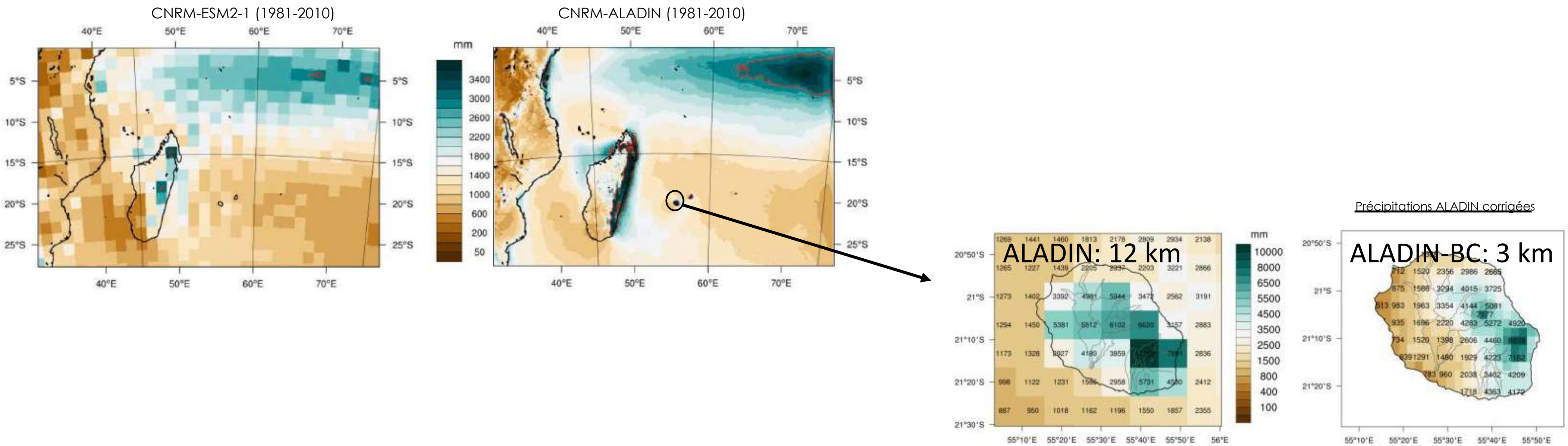
LOCAL SCALE

E.g., Regionalization of precipitations



Why and how we downscale

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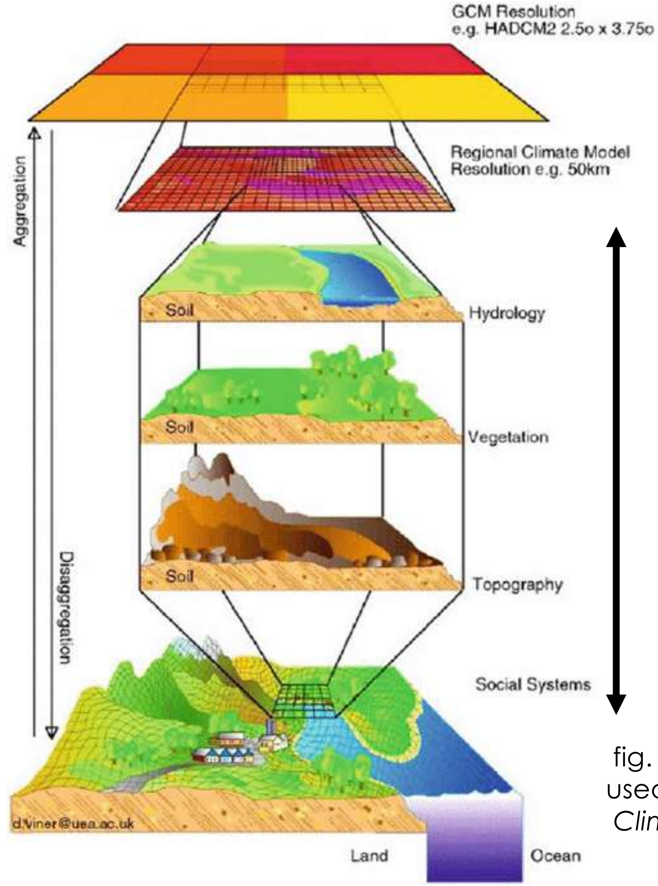
LOCAL SCALE

Why?

- To **enhance the representation of climate variability**, including extreme events such as heatwaves, heavy rainfall, and droughts

- To **support impact assessments of climate change** on various socio-economic sectors like hydrology, ecosystems, public health, and **energy**



Global climate scenarii
100-300 km

Regional climate scenarii
10-50 km

Impact models
a few km to a few m

fig. 9. **Climate scenarii and models** used in the downscaling procedure *Climate Research Unit University of East Anglia*

Why and how we downscale

GLOBAL SCALE

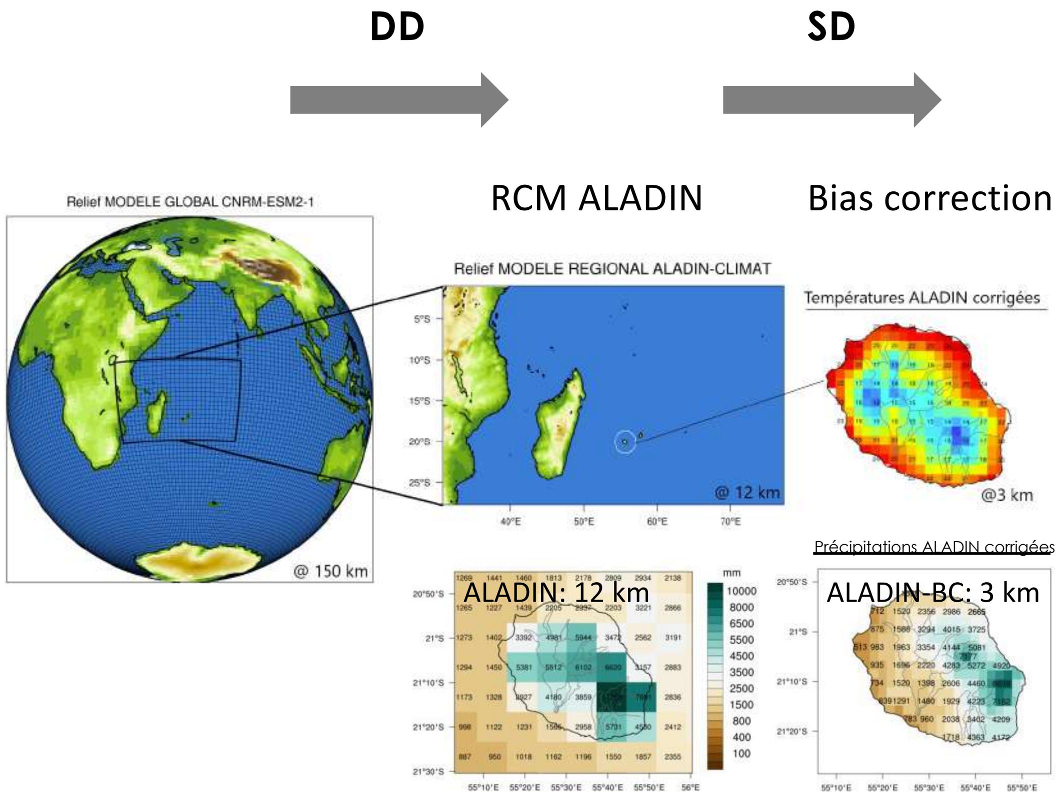
Downscaling: a technique that facilitates **regionalizing** weather/climate information to a **local scale** by utilizing data from a broader, **large-scale** context

LOCAL SCALE

How?

Two complementary approaches:

- **dynamical** downscaling (DD)
  - Uses outputs from a GCM as input for a RCM (e.g., ALADIN, WRF)
  - Relies on physical laws to compute dynamic solutions
- **statistical** downscaling (SD)
  - Establishes statistical relationships between large-scale predictors and fine-resolution predictands
  - Requires training and is constrained by observational data



Why and how we downscale

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  - Requires training and is constrained by observational data

tab. 3. **Comparison** of methods: advantages and disadvantages

Method	Advantages	Disadvantages
Dynamical downscaling (DD)	• Physically based, account, for complex processes • Suitable for regions with limited observational data • Provides comprehensive spatio-temporal detail	• Computationally intensive and time-consuming • Requires high-quality input from GCMs • May still have biases inherited from GCMs
Statistical downscaling (SD)	• Computationally efficient and faster to implement • Captures site-specific relationships effectively • Easier to customize for specific variables or applications	• Depends heavily on the availability and quality of observational data • Assumes stationarity in statistical relationships, which may not hold under changing climates • May oversimplify complex physical processes

Why and how we downscale

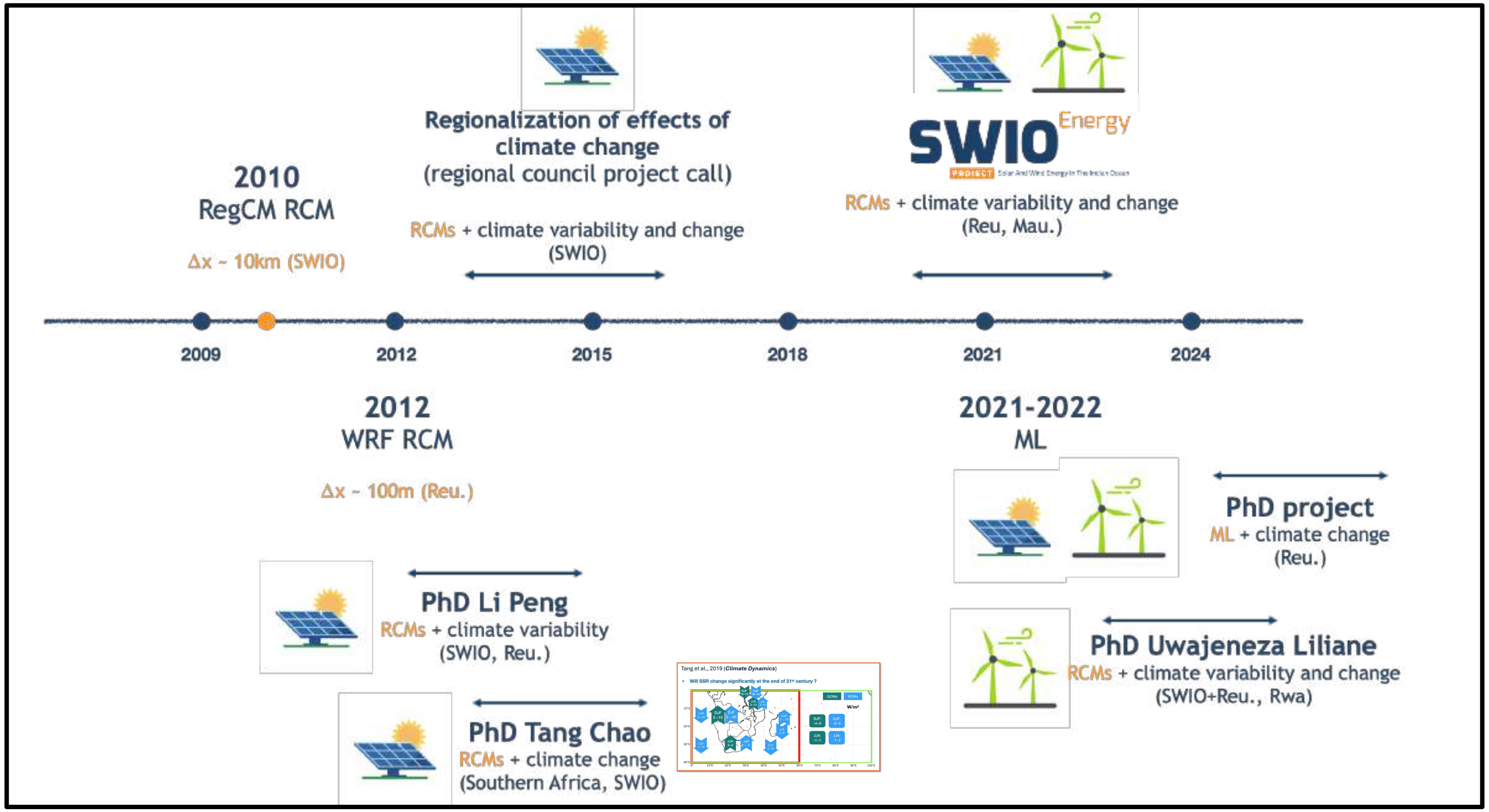
GLOBAL SCALE

Downscaling: a technique that facilitates **regionalizing** weather/climate information to a **local scale** by utilizing data from a broader, **large-scale** context

LOCAL SCALE

Downscaling at ENERGY-Lab?

A bit of history!



Application

BRIO project (2018-2020)

ELSEVIER
Climate Services
Volume 34, April 2024, 100491

Original research article

Developing climate services for vulnerable islands in the Southwest Indian Ocean: A combined statistical and dynamical CMIP6 downscaling approach for climate change assessment

Marie-Dominique Leroux [a], François Bonnardot [c], Samuel Somot [b], Antoinette Alias [b], Stephason Kotomangazafy [c], Abdoul-Oikil Saïd Ridhoine [d], Philippe Veerabadren [e], Vincent Amélie [f]

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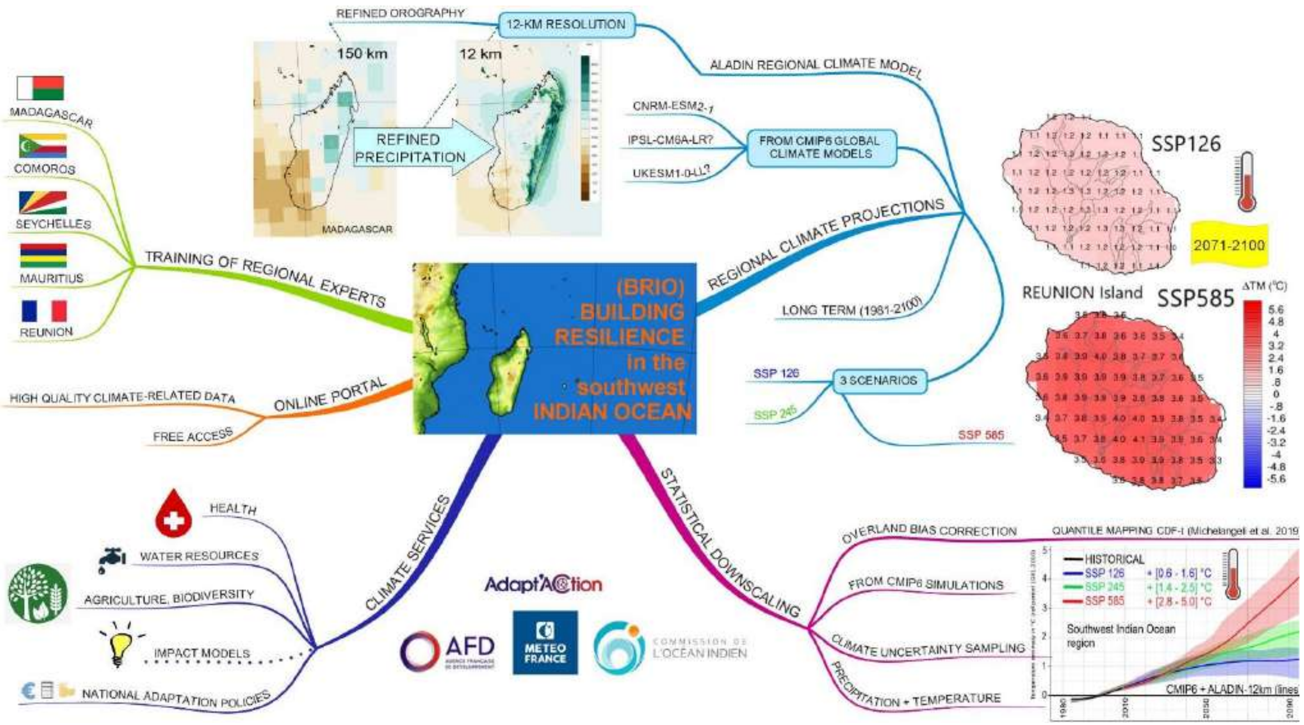
Highlights

- Multiple approaches to produce climate services within a resource-constrained context.
- A potential framework model for other vulnerable regions with limited CORDEX coverage.
- A dry season expected to become drier in most of the Southwest Indian Ocean.
- An expected increasing tropical cyclone risk per event in the Southwest Indian Ocean.



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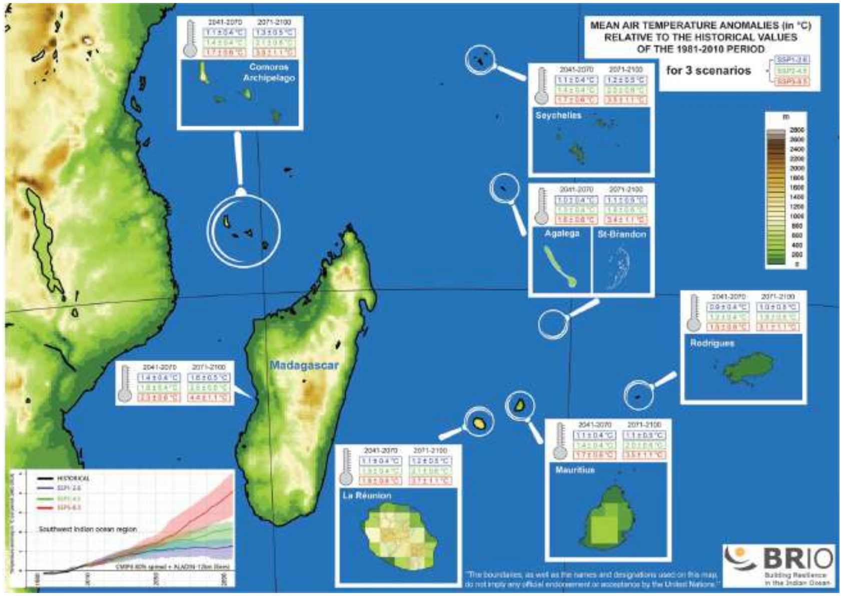
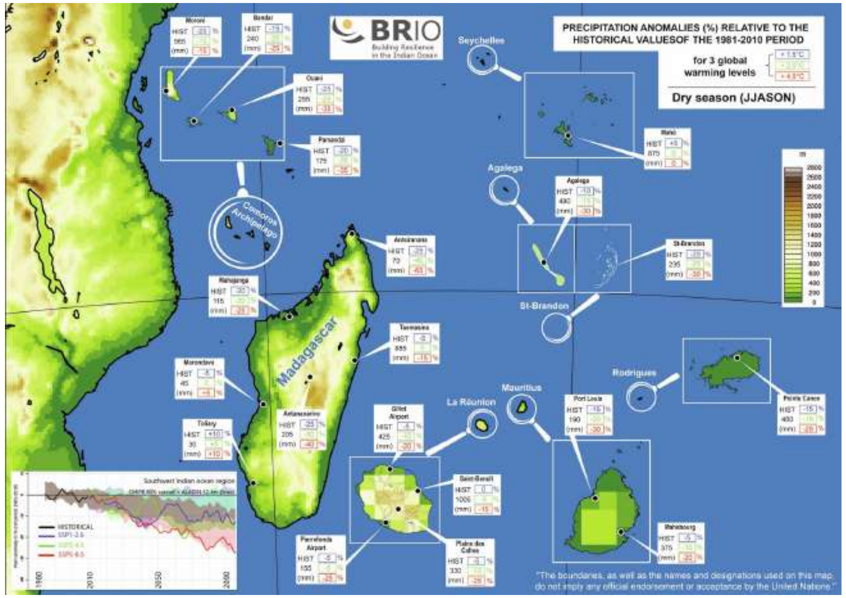


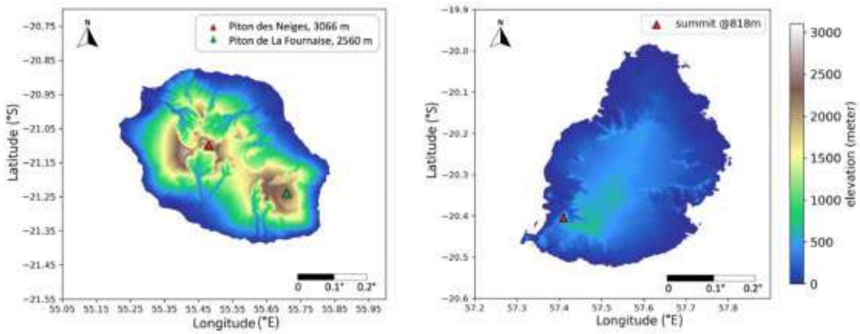
What are the impacts on **energy** in Reunion and the SWIO region?

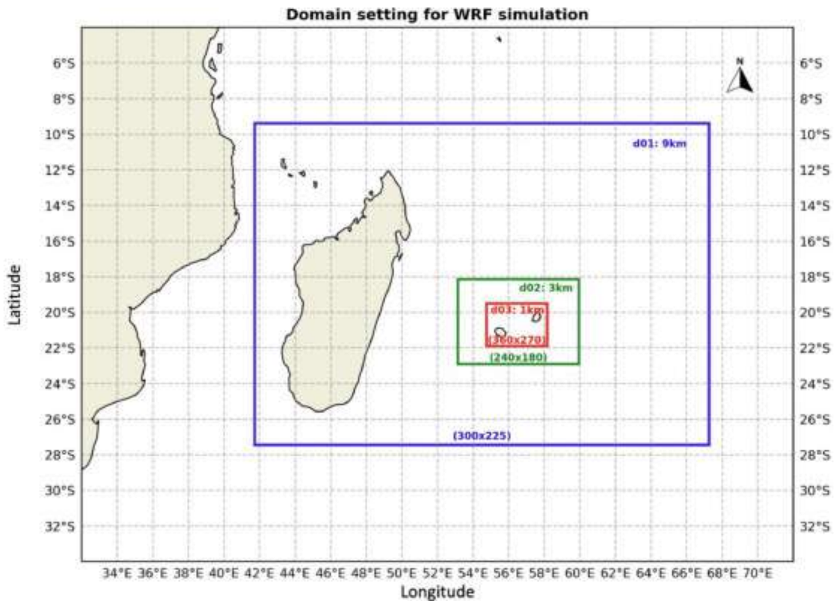


Application

SWIO-Energy project (2020-2023)

Impact of Climate Change on Solar and Wind energy in the SWIO (Reunion, Mauritius)





Simulation features	
forcing data	ERA5 @25 km spatial resolution and every 6 hr on pressure levels
spatial resolution	9 km -> 3 km -> 1 km

Application

SWIO-Energy project (2020-2023)
Impact of Climate Change on Solar and Wind energy in the SWIO (Reunion, Mauritius)

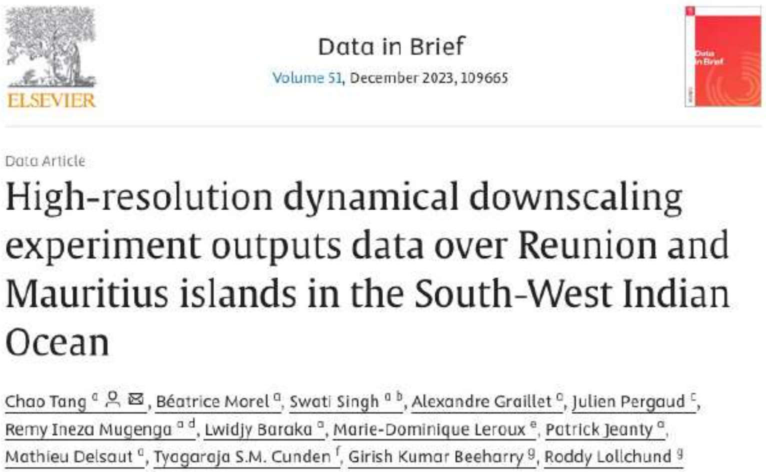
The **physical configuration** of the WRF simulation was decided based on **previous simulations** and **sensitivity tests**, where hourly surface air *temperature*, surface solar *radiation*, and 10-meter *wind speed* and direction for **2017** were compared with ground-based measurements from Météo-France in Reunion and from IOS-net in Mauritius.

Planetary Boundary Layer	Cumulus	Microphysics	Community Land Model	Assigned name
Yonsei University scheme (YSU)	Kain-Fritsch (KF)	WRF Single-Moment 6-class (WSM6)	Noah	WRF1
√ Mellor-Yamada-Janjic scheme (MYJ)	Kain-Fritsch (KF)	WRF Single-Moment 6-class (WSM6)	Noah	WRF2
Yonsei University scheme (YSU)	Kain-Fritsch (KF)	Morrison 2-moment (MDM)	Noah	WRF3
Yonsei University scheme (YSU)	Kain-Fritsch (KF)	Morrison 2-moment (MDM)	Community Land Model (CLM)	WRF3*
Mellor-Yamada-Janjic scheme (MYJ)	Kain-Fritsch (KF)	Morrison 2-moment (MDM)	Noah	WRF4
Yonsei University scheme (YSU)	Grell-Devenyi (GD)	WRF Single-Moment 6-class (WSM6)	Noah	WRF5
Mellor-Yamada-Janjic scheme (MYJ)	Grell-Devenyi (GD)	WRF Single-Moment 6-class (WSM6)	Noah	WRF6
Yonsei University scheme (YSU)	Grell-Devenyi (GD)	Morrison 2-moment (MDM)	Noah	WRF7
Mellor-Yamada-Janjic scheme (MYJ)	Grell-Devenyi (GD)	Morrison 2-moment (MDM)	Noah	WRF8

Application

SWIO-Energy project (2020-2023)

Impact of Climate Change on Solar and Wind energy in the SWIO (Reunion, Mauritius)



Data in Brief
Volume 51, December 2023, 109665

Data Article

High-resolution dynamical downscaling experiment outputs data over Reunion and Mauritius islands in the South-West Indian Ocean

Chao Tang[a], Béatrice Morel[a], Swati Singh[a b], Alexandre Graillet[a], Julien Pergaud[c], Remy Ineza Mugenga[a d], Lwidjy Baraka[a], Marie-Dominique Leroux[e], Patrick Jeanty[a], Mathieu Delsaut[a], Tyagaraja S.M. Cunden[f], Girish Kumar Beeharry[g], Roddy Lollchund[g]

DOI: 10.1016/j.dib.2023.109665

Simulation features	
forcing data	ERA5 @25 km spatial resolution and every 6 hr on pressure levels
spatial resolution	9 km -> 3 km -> 1 km
temporal coverage	30 years from 1990 **(already avail. 1990-2016)**
output frequency	30 min, 1 hr, 3 hr, 6 hr, 1 dy
output variable	64 variables: radiation/energy fluxes, meteorological data, e.g., temp, pr, RH, pressure... at the surface and on pressure levels
total output size	*40 Tb*
data access	open data https://galilee.univ-reunion.fr/
calculation time	432 x 720 CPU hours / simu-year (3% waiting time) (~ 1 month to simulate a year) **Simulation started in Sep. 2022!**

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Value of the data

- **Weather forecasting:** Provides detailed insights into local and regional climate trends for improved forecasting accuracy
- **Climate change detection:** Enables the identification of past impacts, essential for developing adaptation and mitigation strategies.
- **Intermittent climate-related energy resources analysis:** Assesses spatiotemporal variability of solar, wind, and hydro resources, supporting the energy transition.
- **Data validation:** Enables comparison with ground-based, satellite, and other model datasets for evaluation purposes.
- **Study of physical processes:** Facilitates fine-scale analysis of climate dynamics for a better understanding of local impacts.
- **Study of topography effects:** Allows the study of topographic influences on climate by comparing two isolated islands with contrasting landscapes.

Conclusion

What's Coming Next?

Role of hydrogen in the islands…