ENSO Metrics: Status & Next Steps

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with contributions from
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ENSO Metrics: Background

CLIVAR Research Focus: ENSO in a Changing Climate
http://www.clivar.org/research-foci/enso
2014-2018; then merged back into CLIVAR PRP
Co-chairs: E. Guilyardi (IPSL) & A. Wittenberg (NOAA GFDL)
Implementation & application: Yann Planton (IPSL/PMEL)
12 ENSO experts (France, US, Australia, Japan, Korea, UK)

Goals:
- Understand ENSO processes & past/future changes
- Develop evaluation protocol for ENSO in GCMs
- Target obs to improve models & projections

ENSO Performance: Andrew, Yann, Antonietta, Mike, Matt, Scott, …
Teleconnections: Scott, Yann, Shayne, Cai, …
Processes: Yann, Eric, Soon-Il, Fei-Fei, Tobias, …

Community package liaisons:
PMP: Jiwoo Lee & Peter Gleckler (PCMDI)
ESMValTool: Veronika Eyring (DLR); Bryan Lawrence (NCAS); Barcelona (BSC)
CliMAF: Jérôme Servonnat (IPSL)
ENSO metrics strategy

Start with a small subset of **essential, simple** metrics.
Avoid getting bogged down with complexity
Aim more at model *users* than model developers.
Expand as code, interfaces, use-cases take shape.

Metrics (scalars) are first step in a **diagnostic hierarchy**
Useful for intercomparing models & metrics
Dive-down diagnostics: Scalar → 1d → 2d → 3d
Want to see both “forest” and “trees”.

Account for:
- **Internal variability** (multiple historical ensemble members)
- **Obs uncertainties** (use multiple obs products, epochs)

Written in **Python**
Powerful, flexible
Plugs into community efforts
Metric Requirements

1. **Documentation**: Whys & hows of metric and collection
2. Math **definition** of metric (positive scalar “distance”)
3. Input data **frequency** (monthly, daily, ...) and **grid** (1x1 lat/lon, region, etc.)
4. **Obs** (as many as possible) and **epoch** to use
5. Literature **reference** to show robustness/utility of metric
6. **Sample size** (duration or ensemble) needed for metric to make sense
7. Dive-down **diagnostics** (e.g. the spatial maps used to compute RMSE)
8. **Normalization** to use for multi-model intercomparison (single color bar)
Warm events: SSTA \((°C, y=0, t=\text{Dec}(0))\) detrended, smoothed with 5mo triangle

1961–2016 composite, \textbf{Dec}(0) NINO3 SSTA > 0.75°C

- **obs** (15 events)
- **model** (63 events, 5 members)

RMSE: 0.26

- SSTAs extend too far west
- **double peak**
Warm events: NINO3 SSTA (°C)
detrended, smoothed with 5mo triangle
1961–2016 composite, Dec(0) NINO3 SSTA > 0.75°C

obs (15 events)
model (63 events, 5 members)

RMSE: 0.25

EN duration
Inter-EN spacing
delayed termination
ENSO lifecycle
Inter-LN spacing
excessive overshoot
ENSO performance

RMSE-based metrics

- Colors: relative to median value of metric (last column)
- Numbers: metric value

numbers: RMSE relative to obs (perfect score is 0)
colors: medians from inter-model median

different composite thresholds

* = CMIP6
Dive-down diagnostics: Annual-mean SST

Metric:
RMSE\((\text{obs, model})\)

\(\text{IPSL-CM6A-LR} = 1.6^\circ\text{C}\)

Dive-down level 1:

\(\text{IPSL-CM6A-LR too cold everywhere}\)

Dive-down level 2:

ERA-Interim

CMIP5

IPSL-CM6A-LR
**ENSO Metrics: Public Release & Documentation**

*Planton et al. (BAMS 2021)*  
"Evaluating climate models with the CLIVAR 2020 ENSO metrics package."

- Documents & demonstrates the package
- CMIP6 models mostly outperform CMIP5, except for some process metrics (e.g., the h → SST coupling worsened)

**CMIP5/6 ENSO Metrics summary**  
[https://pcmdi.llnl.gov/research/metrics/enso](https://pcmdi.llnl.gov/research/metrics/enso)  
- Interactive dive-down diagnostics  
- Pre-computed model metrics for download (JSON & Excel)

**Wiki:**  

**Software:**  
[https://github.com/CLIVAR-PRP/ENSO_metrics](https://github.com/CLIVAR-PRP/ENSO_metrics)
Recent studies using the ENSO Metrics Package

Lee et al. (GRL 2021): “Robust evaluation of ENSO in climate models: How many ensemble members are needed?”
- For CMIP5/6 & LEs, need $N \geq 50$ to constrain ENSO baseline & process metrics
- Less for climatology ($N \geq 6$) & ENSO teleconnections ($N \geq 12$)
  for 95% of $N$-ensemble means (of 1979-2018 metrics) to fall within 10% of actual mean metric

Xu et al. (JC 2022): “The Andes affect ENSO statistics”
- Elevate the Andes to more realistic levels in CESM_1.2.2
  → better (more LN-like) troPac climate
  → weaker ENSO; more asymmetric, irregular, evaporatively-damped

Planton et al. (in prep for JAMES): “Detecting ENSO variance changes in a warmer world.”
- CMIP6 historical runs: Sample size to detect past & future ENSO amplitude changes?
  Need 5 – 9 members, for ensemble-mean 30yr variance to fall within 15% of actual long-term variance
- If ENSO strengthens → more decadal modulation → later detection
- Quiet/hyperactive ENSO decades can aid earlier detection

Lee et al. (in prep for GMD): “Diversifying objective summaries of Earth system model performance: An overview of the PCMDI Metrics Package (PMP).”
- A section is devoted to the ENSO metrics
Community Connections

**CLIVAR/ICTP ENSO Summer School**
Yann Planton developed & ran student tutorials, applying package to CMIP6
→ supported the *WCRP Academy Lighthouse Activity (LHA)*

**Jiwoo Lee** joined the **CMIP7 Climate Model Benchmarking Task Team**
→ Actively promoting the CLIVAR ENSO Metrics via the PMP framework

Connections with other community efforts
- **PMP**, **ESMValTool**, **CliMAF**, **MDTF**
- **ES-Doc** & **Comparator**: model resolution, lineage, parameterization schemes

**Tropical Pacific Observing System (TPOS)**
Obs targeting + new reference data
Next Steps for ENSO Metrics

Leverage recent enhancements
- Added more **obs datasets** to test robustness (Planton et al., in prep)
- **Index statistics**: mean, stddev, skewness, d.o.f. → significance
- **Wait times** between ENSO events: mean, stddev, skewness, PDFs, transition probabilities

New metrics in development
- ENSO regional **teleconnections**: regressions, composites (per McGregor et al. 2022)
- New ENSO **process metrics** (per Chen et al. JC 2021)
  BWJ indices, ML heat budget, nonlinear dynamical heating (NDH)
- Model-analogs as metrics of ENSO **evolution, predictability, forecast skill**
  Applied to NMME & CMIP5 historical: Ding et al. (JC 2018; GRL 2020)
  Applied to CMIP6 & LE, historical & future: Lou et al. (subm. & in prep.)
  + ongoing work at NOAA PSL & GFDL
- CLIVAR PRP Working Group on **Conceptual Models of ENSO**

New & proposed projects:
- Impact of **climate change** on ENSO (Planton, Lee, et al., in prep)
- EqPac **upwelling & mixing** in CGCMs (Wittenberg et al., NOAA CVP), funded 2023-25
- Dynamical ENSO metrics & **emergent constraints** (Jin et al., NOAA MAPP), submitted
Action Items for PRP

1. **Feedback** on metrics, interfaces, development, dissemination

2. Recommend **observational** references
   - Latest *gridded* products, reanalyses
   - How to best characterize obs uncertainties?
   - Best epochs to use?

3. Recommended **realizations** for model & obs (epochs, ensemble sizes)

4. Ideas for new metrics
   - **Expand** existing collections: e.g. connect to **conceptual models**
   - **New collections**: Climate change, teleconnection processes, impacts, …

5. Ideas for applications & tiering of metrics
   - Model evaluation & **selection/weighting**
   - Physical **links** among metrics; **emergent constraints** for future change

6. Resources: **Postdocs**, web/data techs, funding opportunities, …