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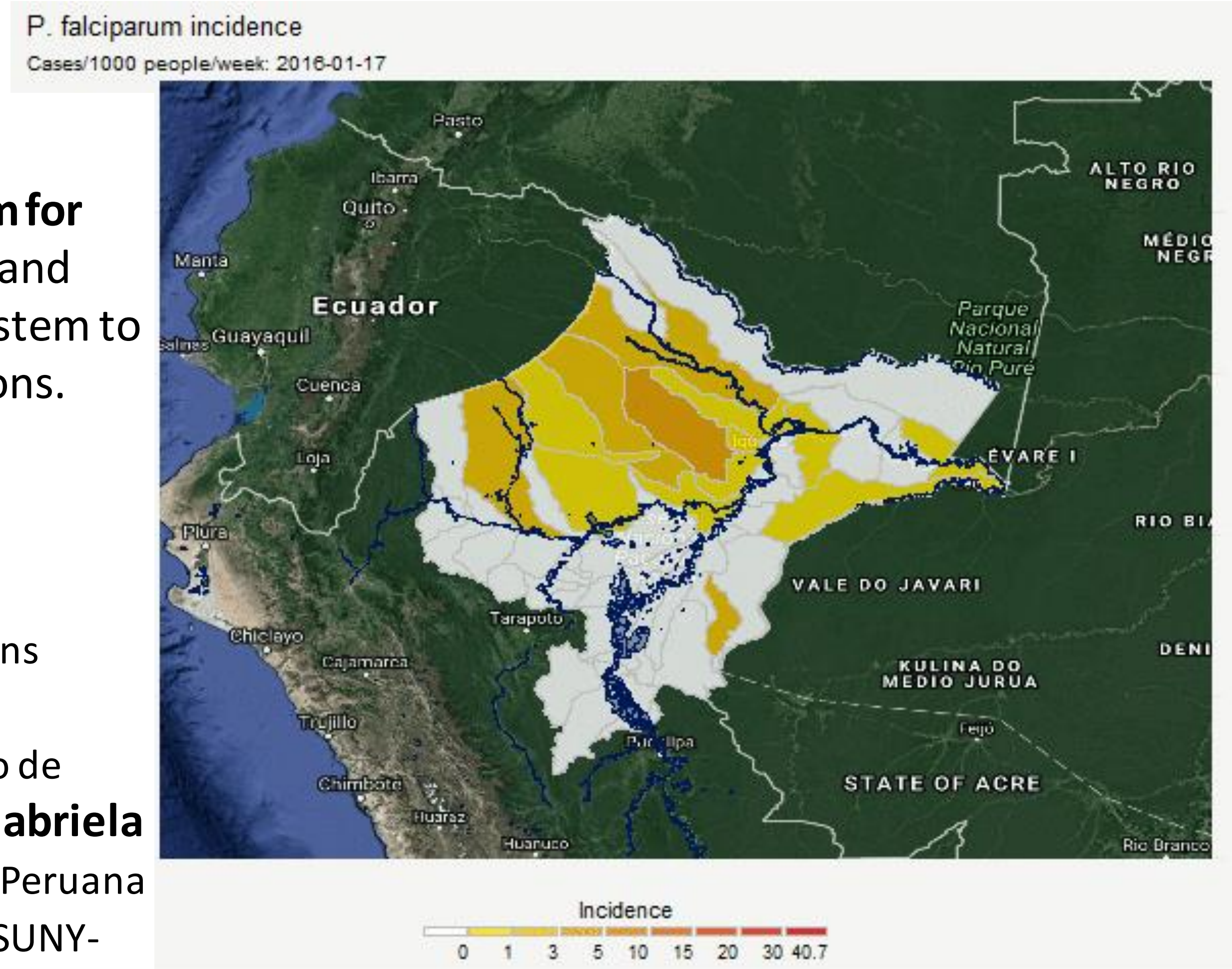
AN EARLY WARNING SYSTEM FOR VECTOR-BORNE DISEASE RISK IN THE AMAZON

NASA PROJECT NNX15AP74G

William Pan, Duke University

Health & Air Quality Applications Program Review, October 2021, Virtualtown, USA

Project Summary



OBJECTIVE

Develop an **early warning system for malaria** in the Peruvian Amazon and evaluate the expansion of the system to other diseases and Amazon regions.

TEAM

William Pan, Duke; **Mark Janko,** University of WA; **Ben Zaitchik,** Johns Hopkins; **Carlos Mena, Francesco Pizzitutti,** Universidad San Francisco de Quito, Ecuador; **Andres Lescano, Gabriela Salmon-Mulanovich,** Universidad Peruana Cayetano-Heredia; **Beth Feingold,** SUNY-Albany; **Cesar Munayco,** CDC-Peru, Ministry of Health

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Summary of Accomplishments

- We forecast malaria outbreaks in small, administrative districts 12 weeks in advance with ~90% sensitivity
- IMPLEMENTATION:
  - LDAS implementation in Ecuador in the Institute of Geography at USFQ in partnership with the Ministry of Public Health
  - Forecasting capacities to be adopted by CDC-Peru and CLIMA (Climate and Infectious Disease Laboratory at UPCH, Lima)
  - Partnership with the InterAmerican Institute for Global Change Research
- Additional Funding:
  - Finalist for EU "Early Warning for Epidemics" prize ($5 million euros)
  - Newly funded R01 from NIAID ($2.5 million) for expansion & cross-border malaria
- Publications: >10 (2 more in review/resubmit)
- Fully costed or encumbered

The rest of this presentation …

Summary of Methods

- How do we achieve 90% sensitivity in detecting malaria outbreaks?
    - LDAS
    - Ecoregion analysis & District level forecast models

Project Plans after NASA (R01, EC Prize)

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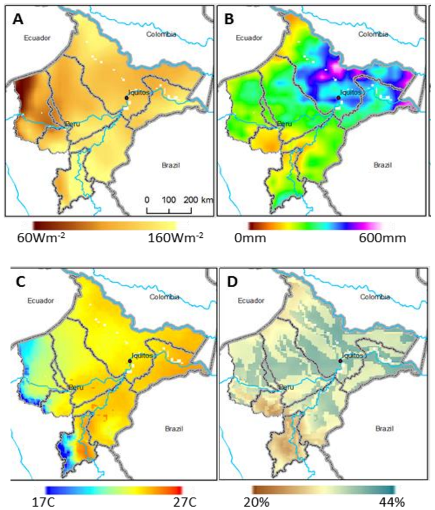
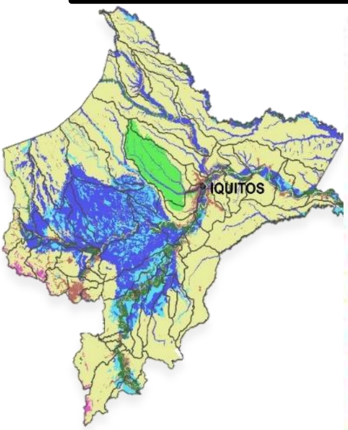
LAND DATA ASSIMILATION SYSTEM

- Temperature
- Precipitation
- Soil Moisture
- Solar Radiation
- Stream Flow



LANDSCAPE ECOLOGY



Districts (n=51)
Bodies of Water

Ecoregions

- Humid Amazon Forest
- Humid Andean Forest
- Forest Flooded by Clear-water Rivers
- Forest Flooded by Black-water Rivers
- Anthropic Areas
- Amazonian azonal vegetation (edaphically conditioned)
- Upper Amazon alluvial plains marsh

Government Malaria Surveillance, Interventions & Population at Risk

ECO-REGION FORECAST MODEL — 12-week forecast in Ecoregions

DISTRICT FORECAST MODEL — 12-week forecast in Districts

AGENT-BASED MODELS — Intervention & Control Scenarios

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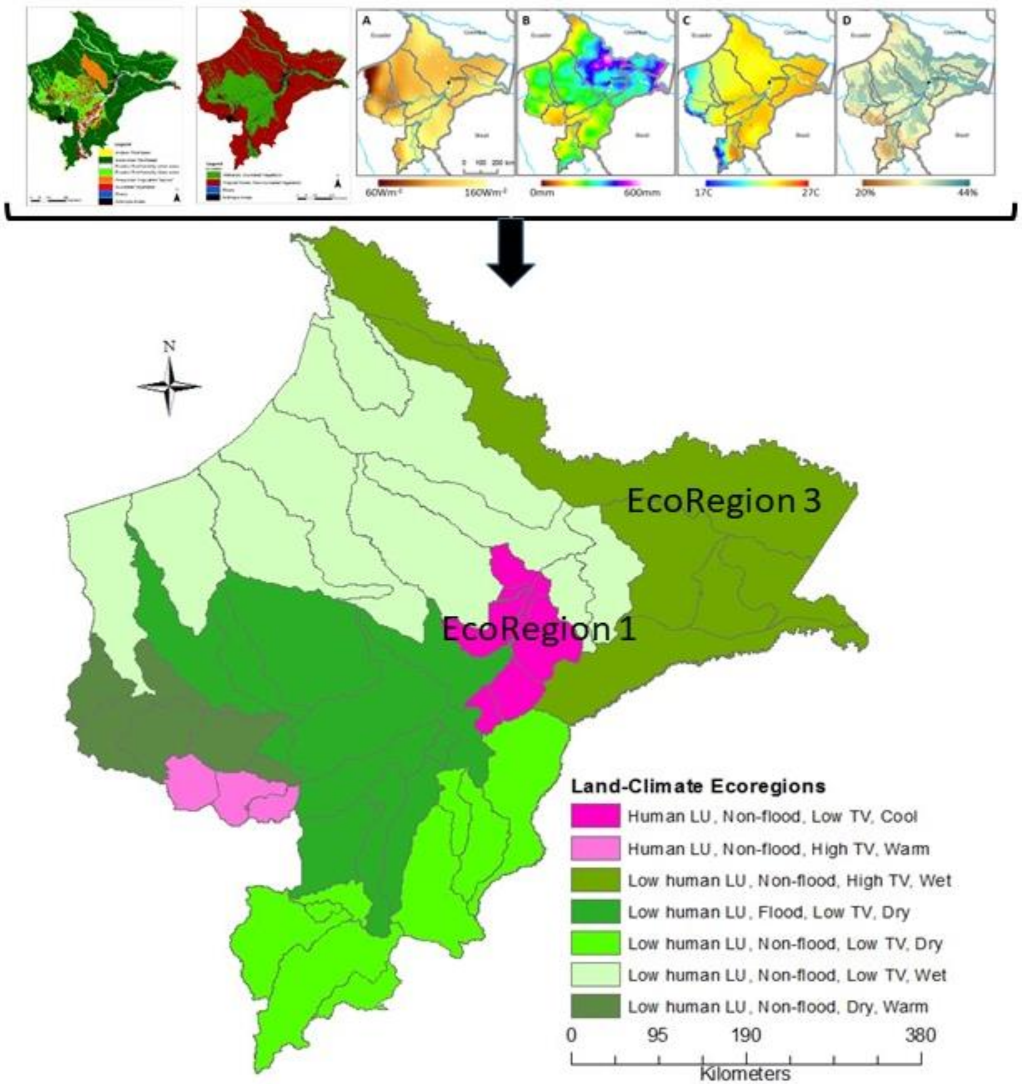
EcoRegion Forecast



- LDAS & Ecosystem data are combined to identify EcoRegions
- Malaria & Population data are aggregated to the EcoRegion level
- Unobserved Component Model (UCM) used to conduct forecasts

$$y_t = \mu_t + \gamma_t + \varphi_t + r_t + \sum_{i=1}^{p} \phi_i y_{t-i} + \sum_{j=1}^{m} \beta_j x_{jt} + \varepsilon_t$$

y_t ~ malaria cases/1000 during week t

μ_t, γ_t, φ_t, and r_t represent the trend, seasonal, cyclical and autoregressive components

ϕ_i is an autoregressive term capturing the momentum of infections

β_j is the unknown effect for explanatory factors

ε_t is the error term

- **MINSA-defined outbreak level**

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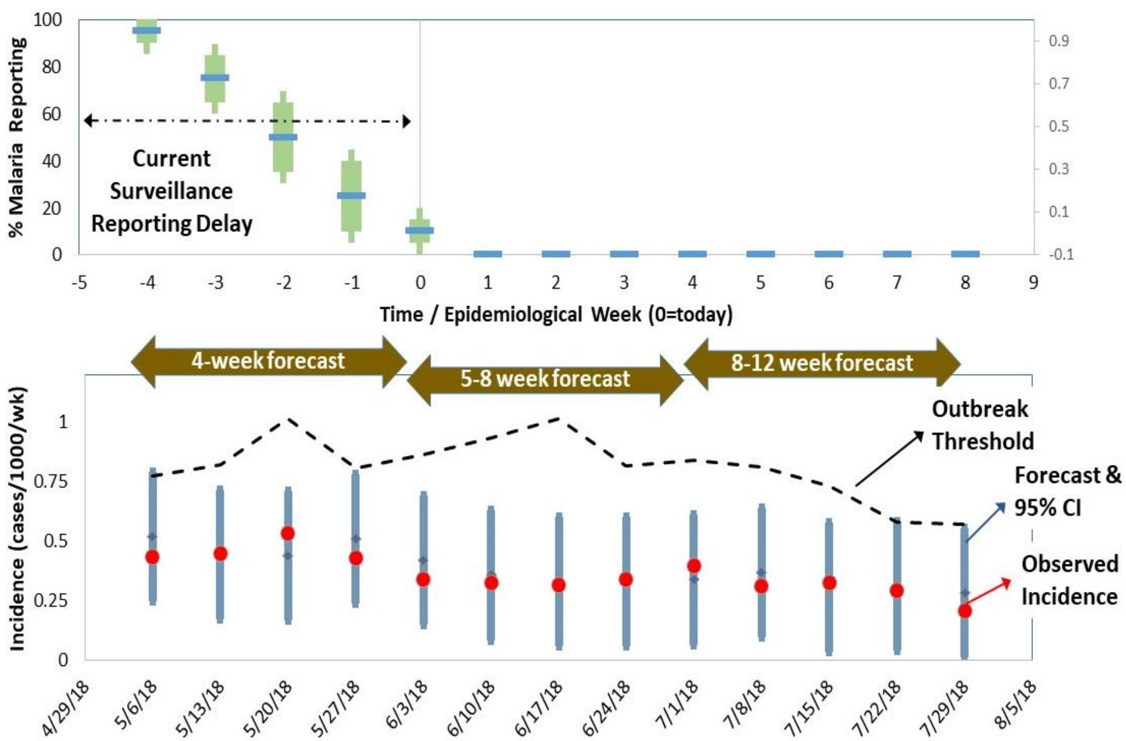
EcoRegion Forecast

Real-time data reporting (top) and forecast (bottom) for EcoRegion 1 from May-July 2018 in Loreto, Peru



Forecast Performance, 2016

	Forecast weeks	TP	FN	FP	TN	Se	Sp
Eco-Region 1	1-4	3	0	0	10	100%	100%
	5-8	3	0	1	9	100%	90%
	9-12	3	0	3	7	100%	70%
Eco-Region 3	1-4	1	1	1	10	50%	91%
	5-8	1	1	1	10	50%	91%
	9-12	2	0	3	8	100%	73%

TP=True Pos; FN=False Neg; FP=False Pos.; TN=True Neg.

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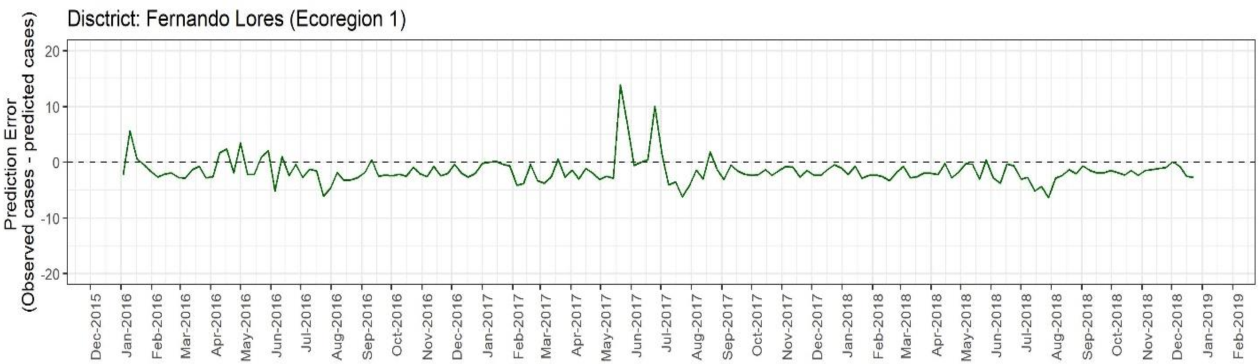
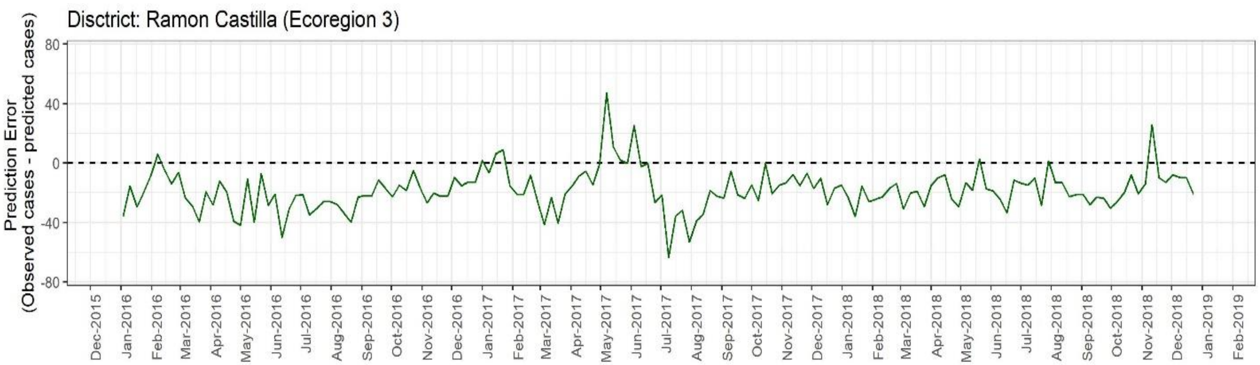
District Level Forecast

Root-mean square prediction error, Fernando Lores and Ramon Castilla districts, 2016-19





Sensitivity & Specificity of 8-week district forecasts, 2007-2019

District	Se	Sp
Ecoregion 1		
Iquitos	88%	84%
Fernando Lores	51%	84%
Punchana	89%	74%
Belen	79%	70%
San Juan Bautista	97%	67%
Jenaro Herrera	94%	98%
EcoRegion 3		
Ramon Castilla	57%	79%
Pebas	54%	68%
Yavari	55%	63%
San Pablo	60%	76%

Hierarchical Bayesian spatio-temporal logistic model

$$y(s,t) = \boldsymbol{x}^T(s,t)\beta + \theta(s,t)$$

$y(s,t)$ ~ # malaria cases in district s during week t
$\boldsymbol{x}(s,t)$ ~ vector of covariates & lagged predictors
$\theta(s,t)$ ~ spatio-temporally correlated random effects

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Life After NASA—R01 Malaria EWS

- NIAID R01: *Improving Response to Malaria Outbreaks in Amazon-Basin Countries*
  - 5 years (Sept 1, 2021-Aug 31, 2026), $2.5 million direct costs

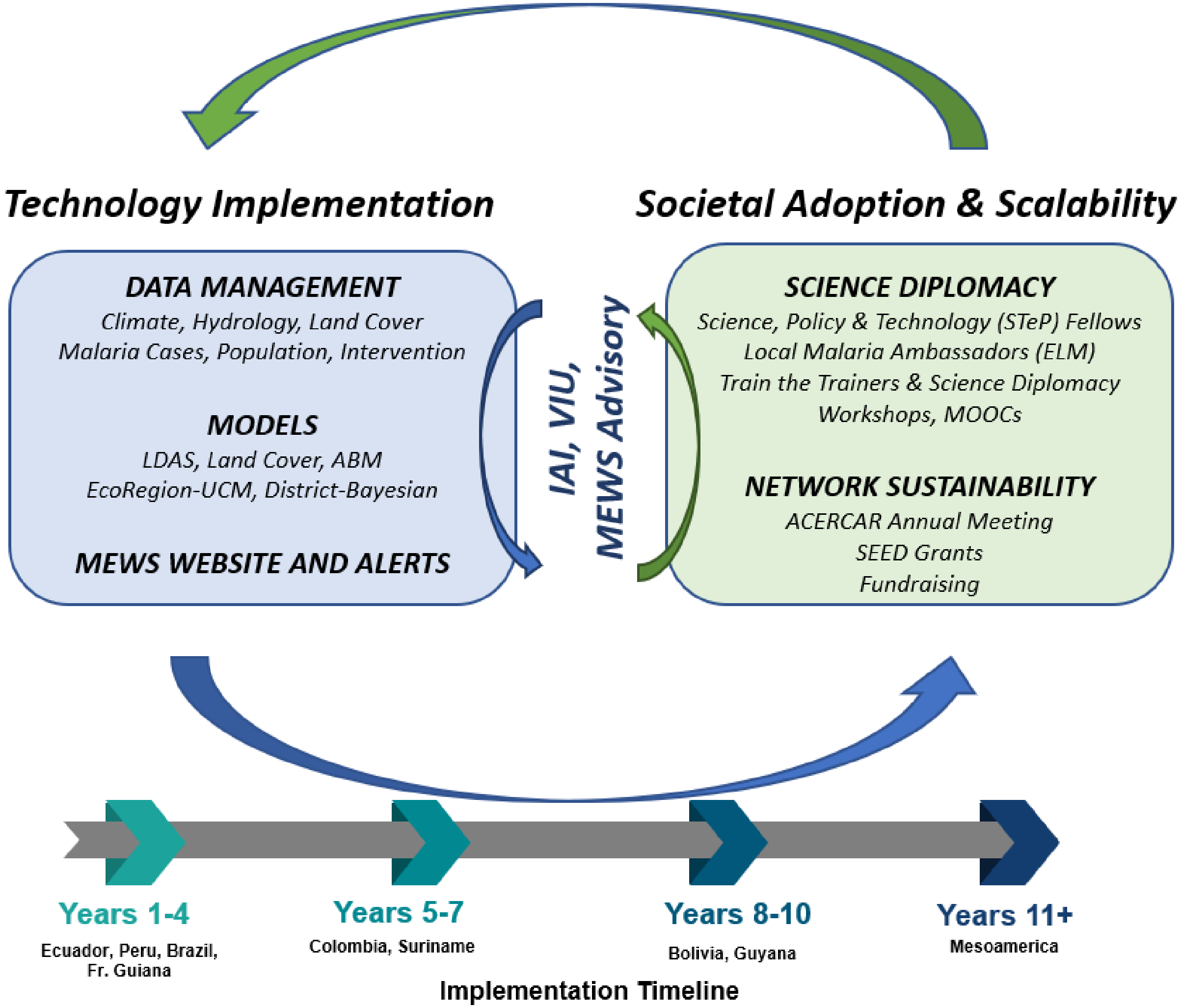
Aim 1. To evaluate (i) MEWS expansion to the Brazilian and Ecuadorian Amazon and (ii) downscaling of forecasts to sub-district levels

Aim 2. To evaluate the relationship between infrastructure, socio-economic networks and migration across international border (Brazil-Peru, Ecuador-Peru) with malaria incidence rates

Aim 3. Evaluate scenarios of potential malaria interventions along borders to jointly reduce malaria rates

Life After NASA—EU Prize

A Consortium to Effectively Respond to Climate-Attributable Risks-Malaria Elimination (ACERCAR-ME)



- Creation of CoP & build Governance Structure around climate-health through STeP Fellow Program led by IAI
- Technology Implementation through partnerships (USFQ and UPCH as model)
- Seeking support from IADB, World Bank, Gates Foundation (& NASA?)

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THANK YOU!

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