

Towards Robust Models of Food Flows and Their Role in Invasive Species Spread

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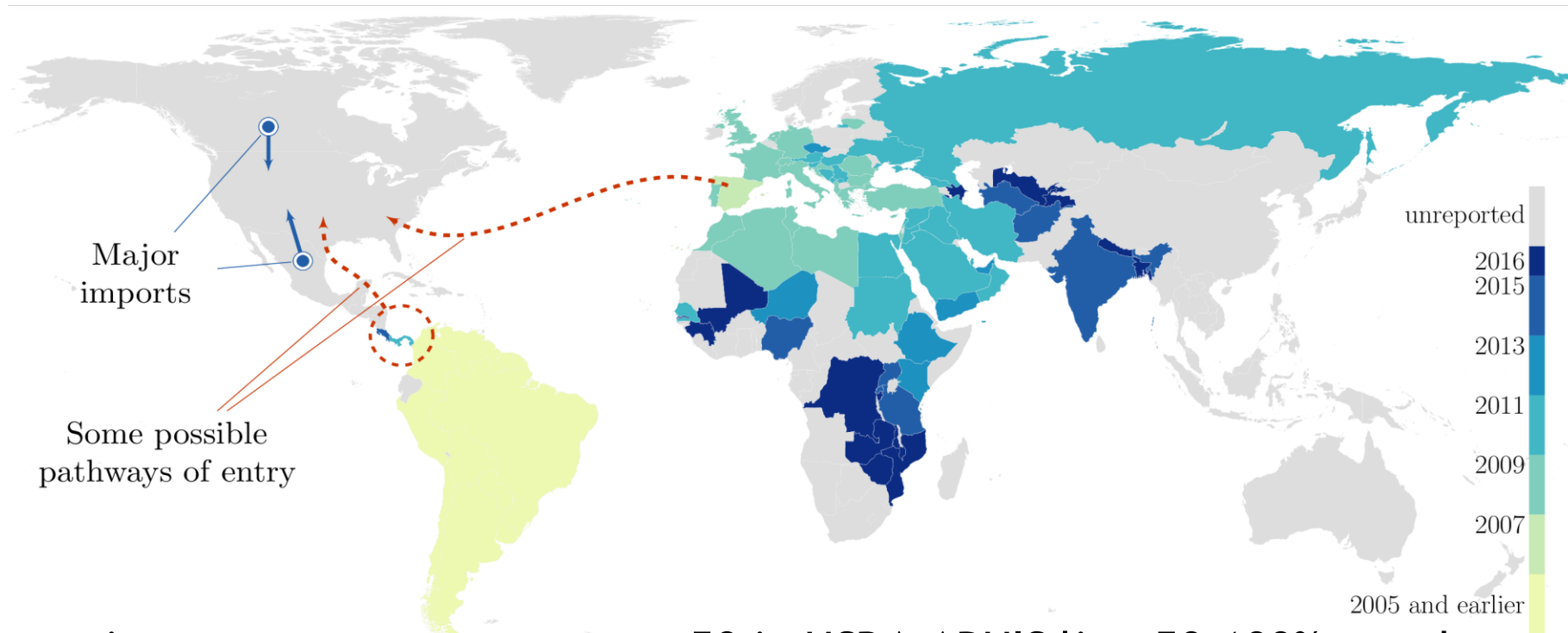
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Motivation

- Global Food Security - one of the challenges of 21st century
 - Growing population and scarce per capita resources
 - Increased globalization, urban migration, food waste
 - Climate change and induced extreme weather events
- Threats of invasive alien species
 - 1/6th of the global land surface is highly vulnerable to invasion¹
 - Substantial areas in developing economies and biodiversity hotspots
 - Role of international trade and travel - wide agreement
- Understanding human-mediated pathways - still nascent
 - Cuniffe et al. Thirteen challenges in modelling plant diseases., Epidemics 2015.

¹ Regan Early et al. Nature Comm 2016, DOI: 10.1038/ncomms12485

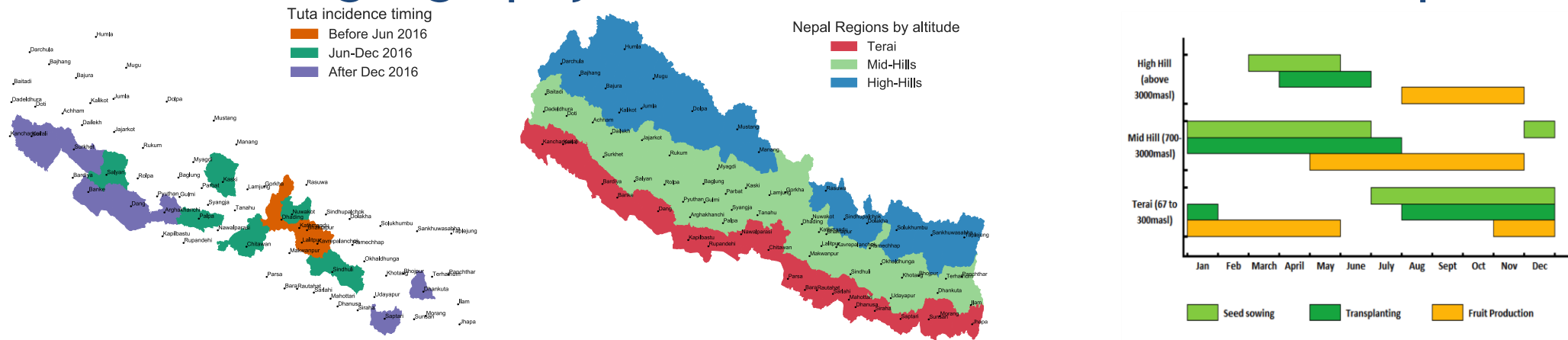
Tuta absoluta - Threat to your Salsa!



- A devastating tomato pest; among top 50 in USDA-APHIS list. 50-100% crop loss
- Can survive in packaging materials, and survives harsh winters and summers in greenhouses.
- **Health costs:** Pesticides (Spain - 15 times in the first year)
- **Financial costs:** Management costs (Netherlands - increase by \$25 M/year)
- **Societal costs:** Sustenance (West Africa - 500K farmers make their living through tomatoes)

Tuta absoluta in Nepal

- First report in Nepal: May 2016, Lalitpur, near Kathmandu
- Rapid spread in the span of six months
- Diverse biogeography - seasonal variations in tomato production



***Tuta* -> Big Data?**

Velocity?



Value?



Variety?



Volume?



Veracity?



Questions & Datasets

- What role has domestic trade played in *T. absoluta* entry and establishment? How will it spread in the future?



- How is tomato produced/transported within Nepal?

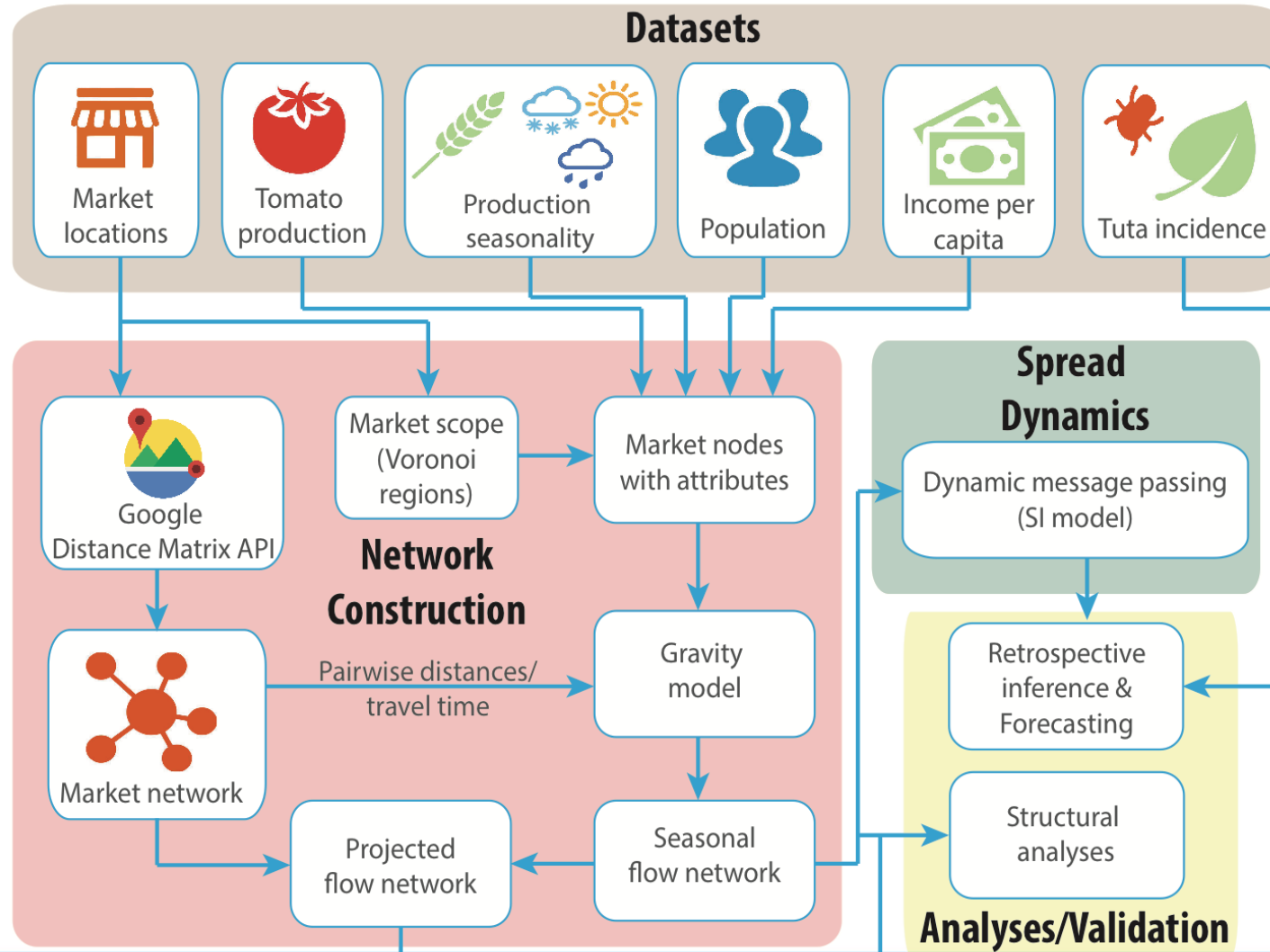


Description	Source	Resolution	Year
Population	Nepal Central Bureau of Statistics (http://cbs.gov.np/)	District/Town	2011
Per Capita Income	Nepal Central Bureau of Statistics (http://cbs.gov.np/)	District	2011
Tomato production	Nepal Ministry of Agricultural Development (MOAD) (http://moad.gov.np/)	District, Annual	2015
Production seasonality	iDE Nepal (http://idenepal.org/) and MOAD	Region, Monthly	2016
Major vegetable markets	MOAD Marketing Information System (http://www.agrimis.gov.np/)	Town	2017
Market distances	Google Maps, Distance matrix API	Market	2017
Tomato import/exports	Food and Agriculture Organization (FAOSTAT) (www.fao.org/faostat/)	Country, Annual	2013
Tomato consumption	FAOSTAT, MOAD	Country, Annual	2013
Flows to Kalimati market	Official website (kalimatimarket.gov.np/)	District, Annual	2015
<i>T. absoluta</i> incidence reports	Nepal National Agriculture Research Council(http://narc.gov.np/) USAID IPM Innovation Lab, iDE Nepal	District/town	2017

Our approach

- Data integration is key to solving this puzzle
 - Multi-type, noisy, misaligned and sparse
 - Context specific domain knowledge (qualitative)
 - Too little data/ground truth for training ML models
 - Need for mechanistic models (physics vs statistics)
- Contributions:
 - Data integration methodology for synthesizing realistic spatio-temporal networks of seasonal agro-products
 - Dynamical analysis of the networks and a novel rank-based inference approach to assess the role of trade in the pest spread
 - Pest spread forecasts with validation/sensitivity analyses

Methodology

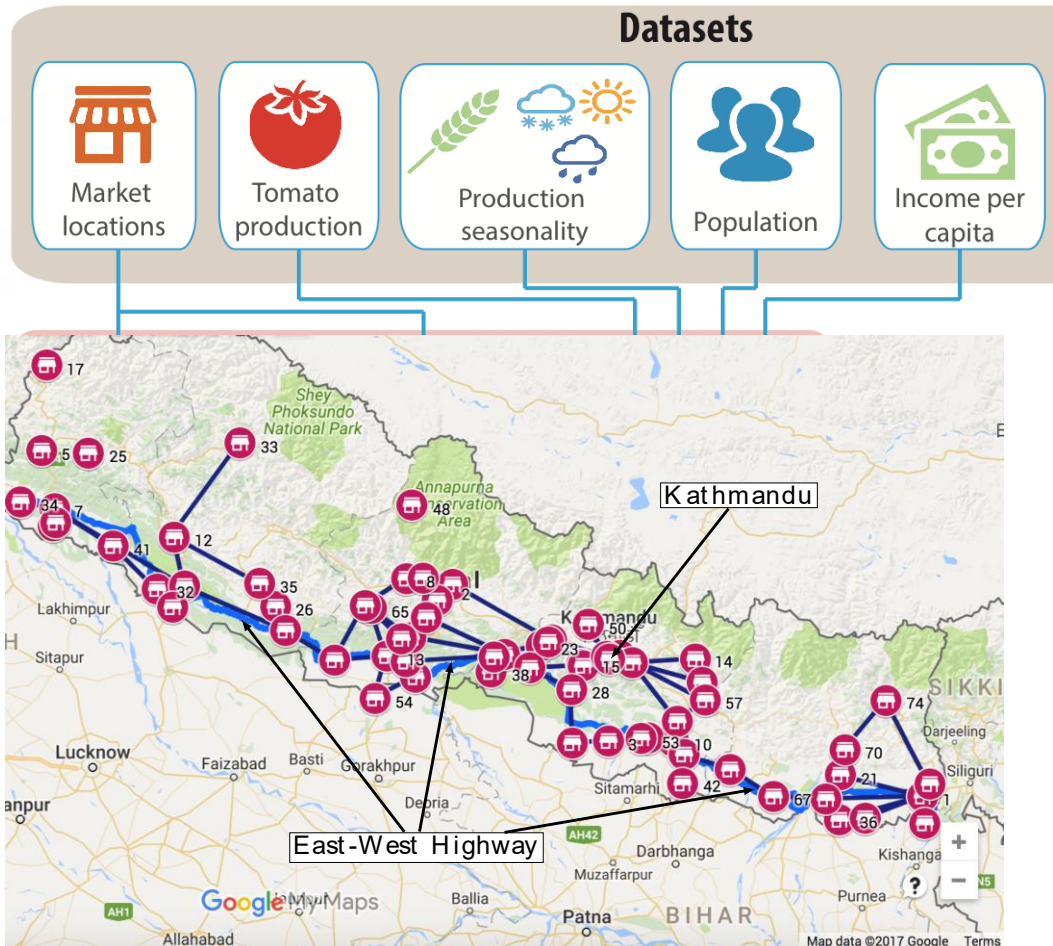


Network Construction

Assumptions:

- Imports and exports are not significant enough to influence domestic trade
 - In 2014, Nepal exported only 1% of its tomatoes and imported about 6-7% of its total consumption (FAO)
- Fresh tomatoes are mainly traded for consumption
 - The tomato processing industry in Nepal is not well developed (USAID/Nepal)
- Using population and per capita income as indicators of tomato consumption
 - Tomato is among the top two profitable vegetables for Nepalese farmers (expensive for typical consumer); not a staple of Nepalese households

Network Construction

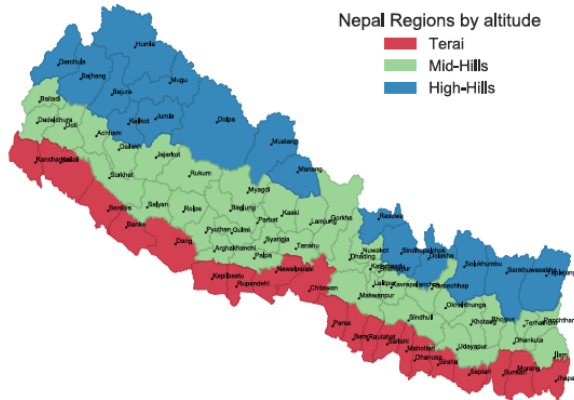


- Doubly constrained gravity model
$$F_{ij} = a_i b_j O_i I_j f(d_{ij})$$
- Income adjusted consumption factor: η_i^γ
- Distance deterrence function
$$f(d_{ij}) = d_{ij}^{-\beta} \exp(-d_{ij}/\kappa)$$
- Google Distance Matrix API to compute travel times by road

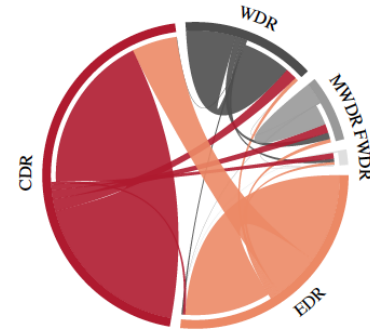
Spatio-temporal dynamics



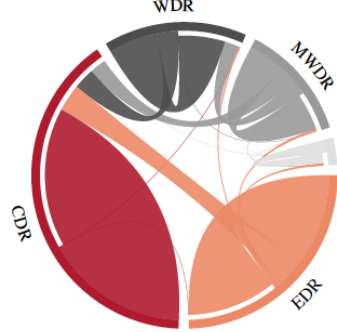
(a) Development regions



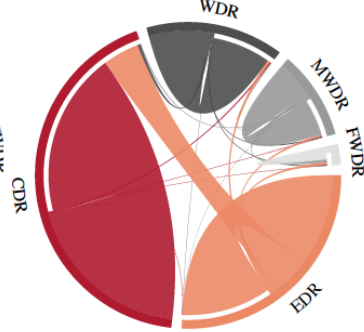
(e) Regions by altitude



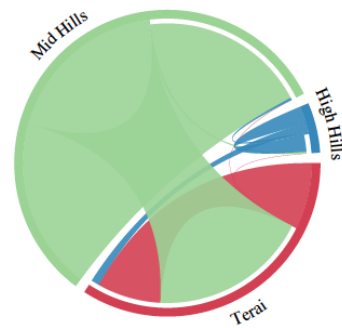
(b) Season S1 (Summer)



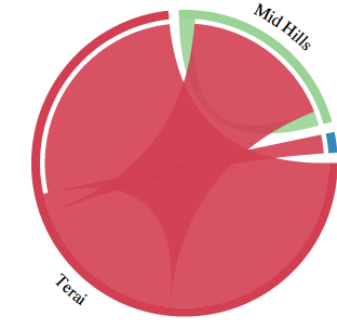
(c) Season S2 (Winter)



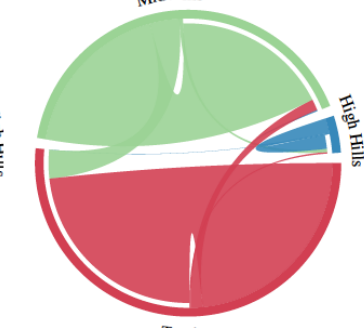
(d) All year



(f) Season S1 (Summer)

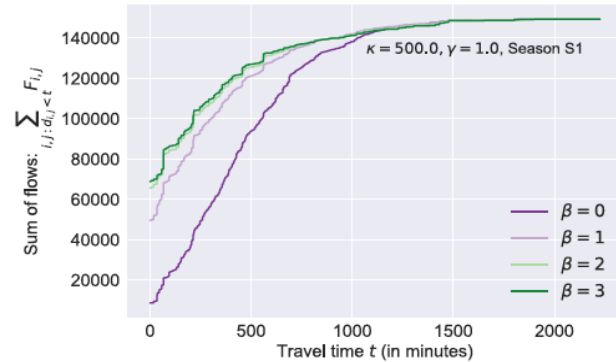


(g) Season S2 (Winter)

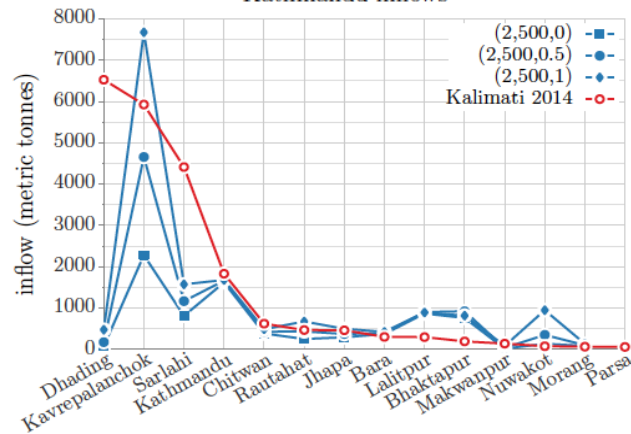


(h) All year

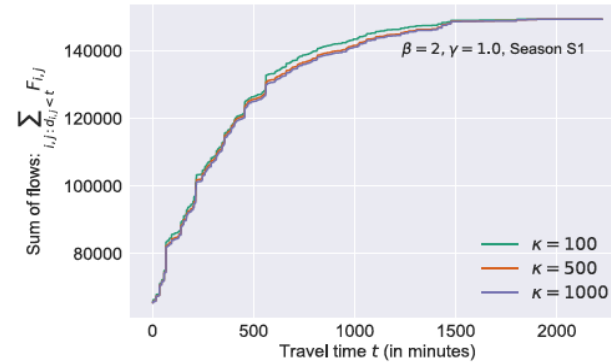
Sensitivity analyses & Validation



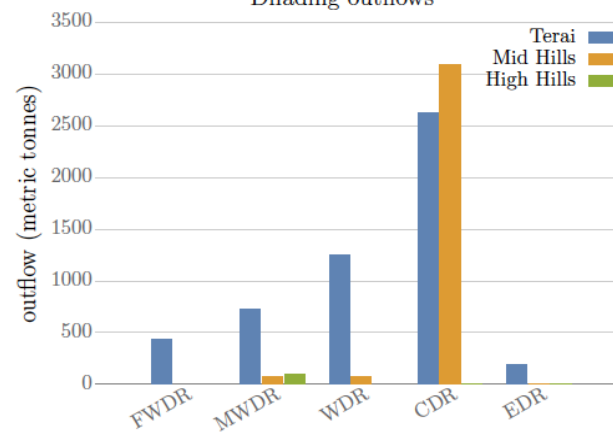
(a) Sensitivity to β
Kathmandu inflows



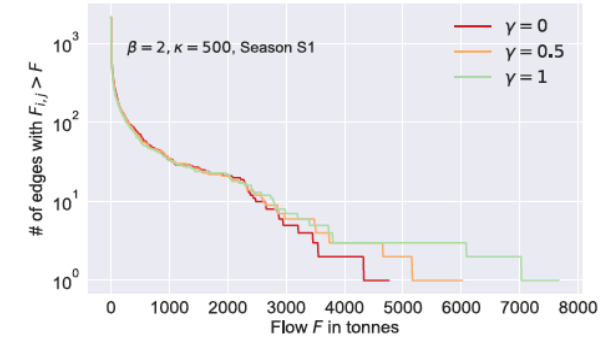
(d)



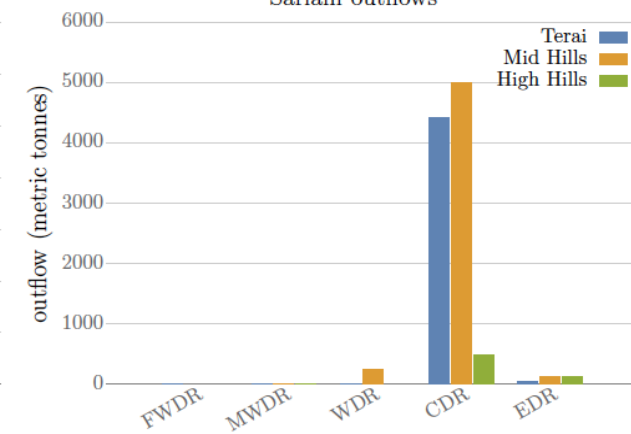
(b) Sensitivity to κ
Dhading outflows



(e)



(c) Sensitivity to γ
Sarlahi outflows



(f)

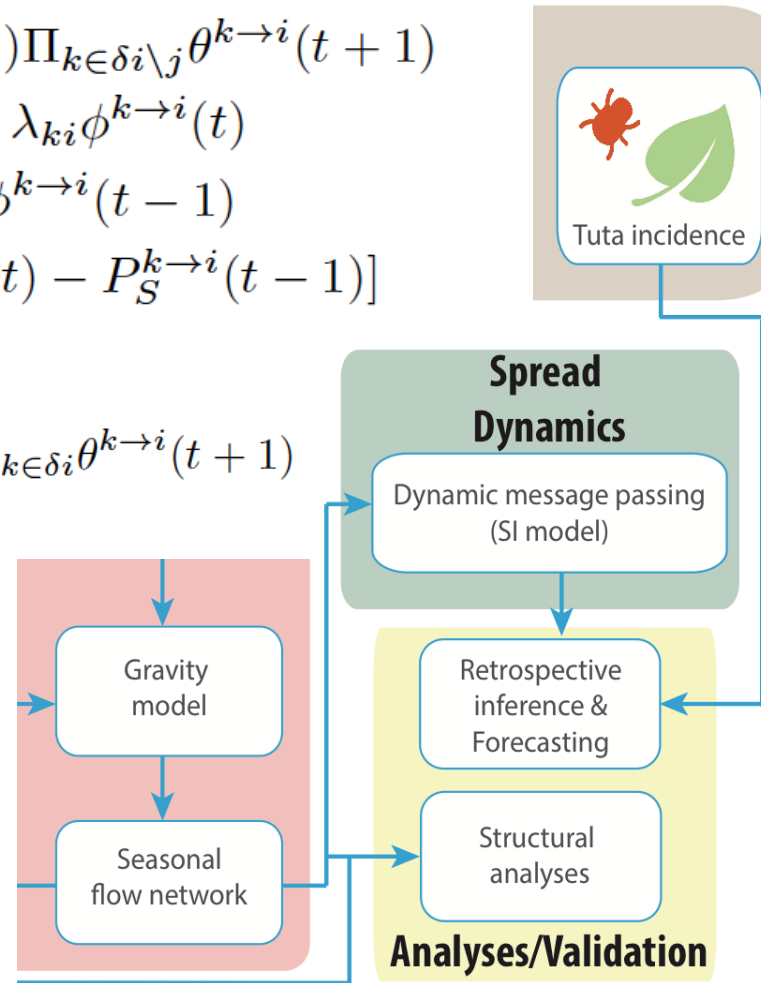
Spread Dynamics

$$P_S^{i \rightarrow j}(t+1) = P_S(i, 0, f_0) \prod_{k \in \delta i \setminus j} \theta^{k \rightarrow i}(t+1)$$

$$\theta^{k \rightarrow i}(t+1) = \theta^{k \rightarrow i}(t) - \lambda_{ki} \phi^{k \rightarrow i}(t)$$

$$\phi^{k \rightarrow i}(t) = (1 - \lambda_{ki}) \phi^{k \rightarrow i}(t-1) - [P_S^{k \rightarrow i}(t) - P_S^{k \rightarrow i}(t-1)]$$

$$P_S(i, t+1, f_0) = P_S(i, 0, f_0) \prod_{k \in \delta i} \theta^{k \rightarrow i}(t+1)$$



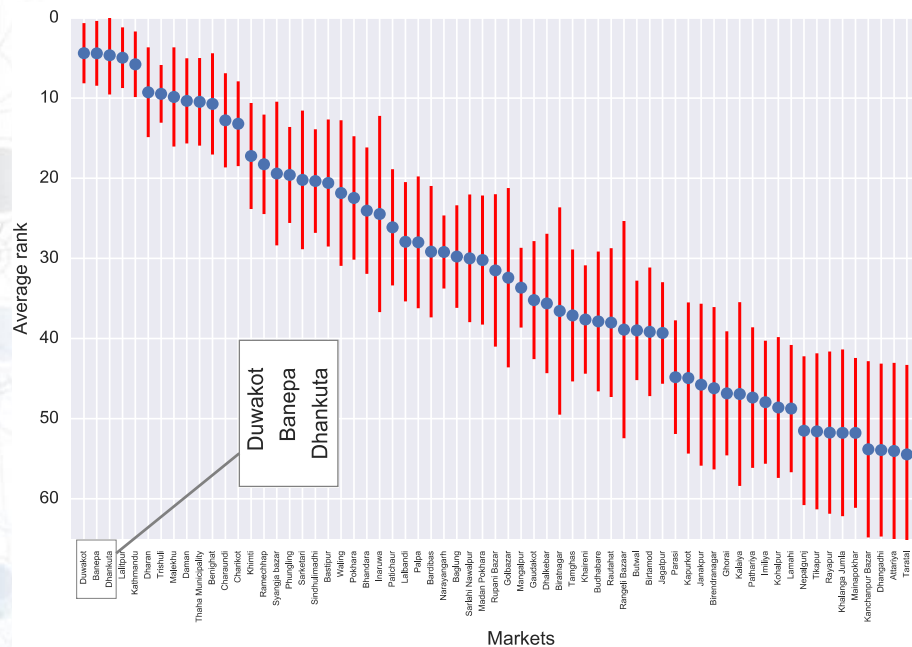
- Discrete time SI (Susceptible -> Infected) model for pest dispersal
- Infection probabilities obtained as a linear function of flow volume
- Message passing algorithm to obtain infection probabilities

Model validation

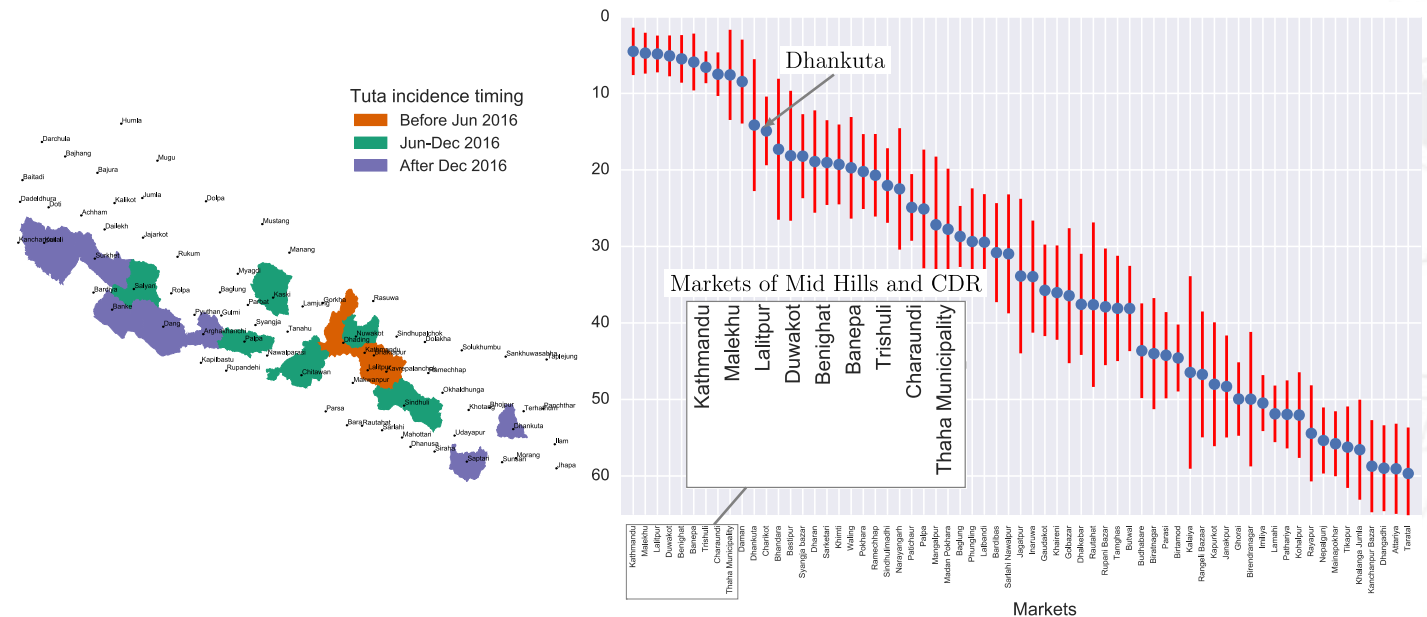
- We used rank-based inference to validate our model
- Framework applicable for inference of invasion origin (source detection)

Scoring function
$$\phi(\mathcal{O}|f_0, t) = -\log \left(\prod_{(v, X) \in \mathcal{O}} P_X(i, t, f_0) \right)$$

Source detection without surveillance



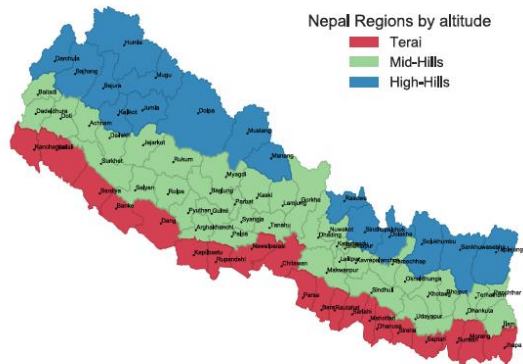
With surveillance data



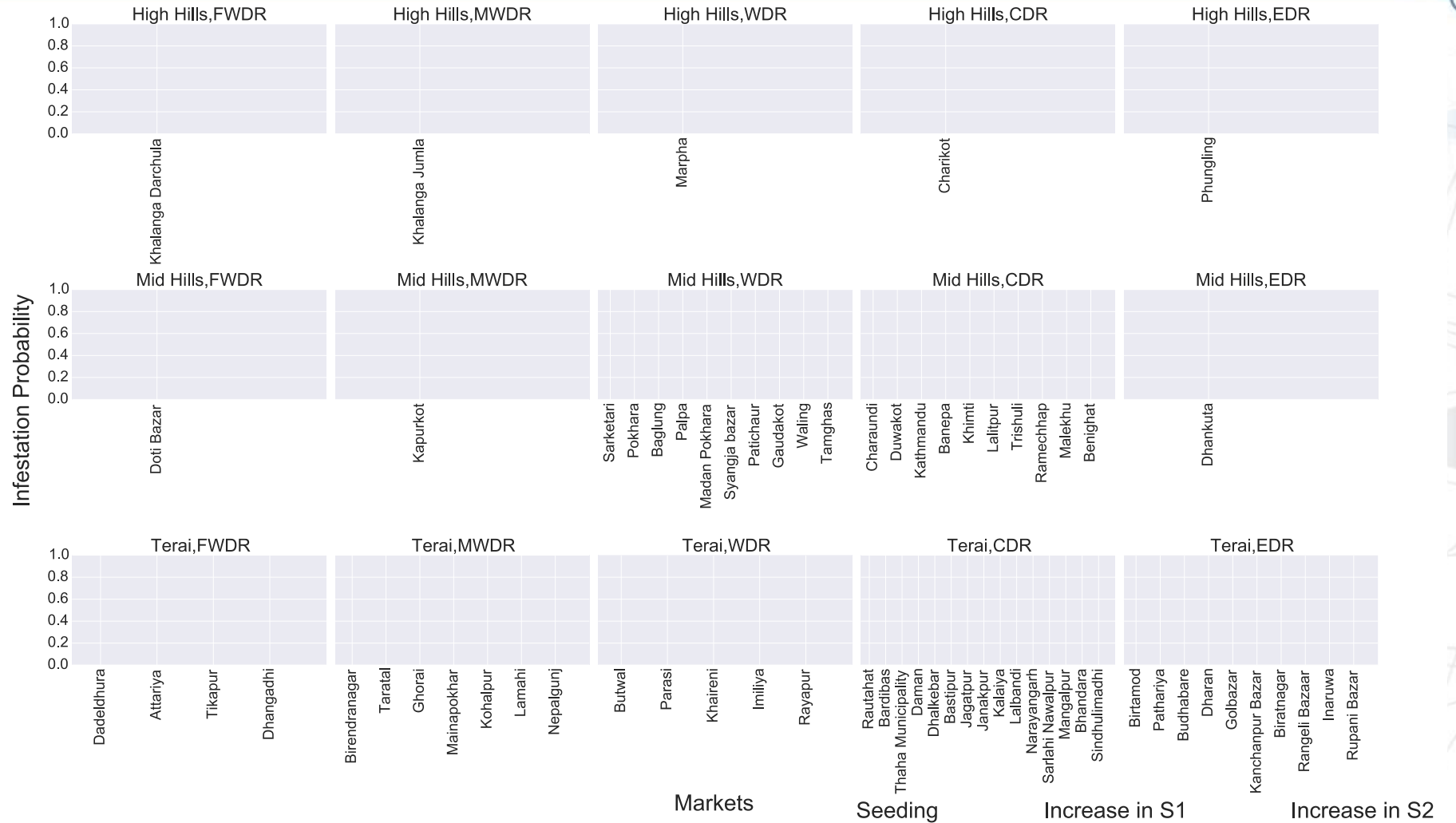
Forecasting



(a) Development regions



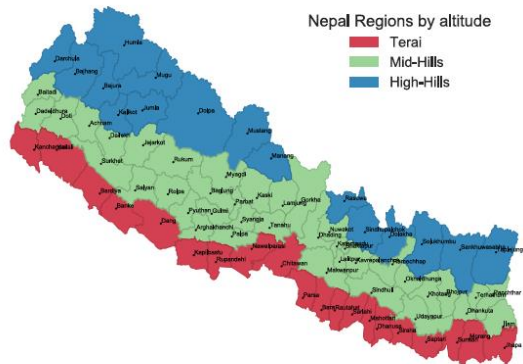
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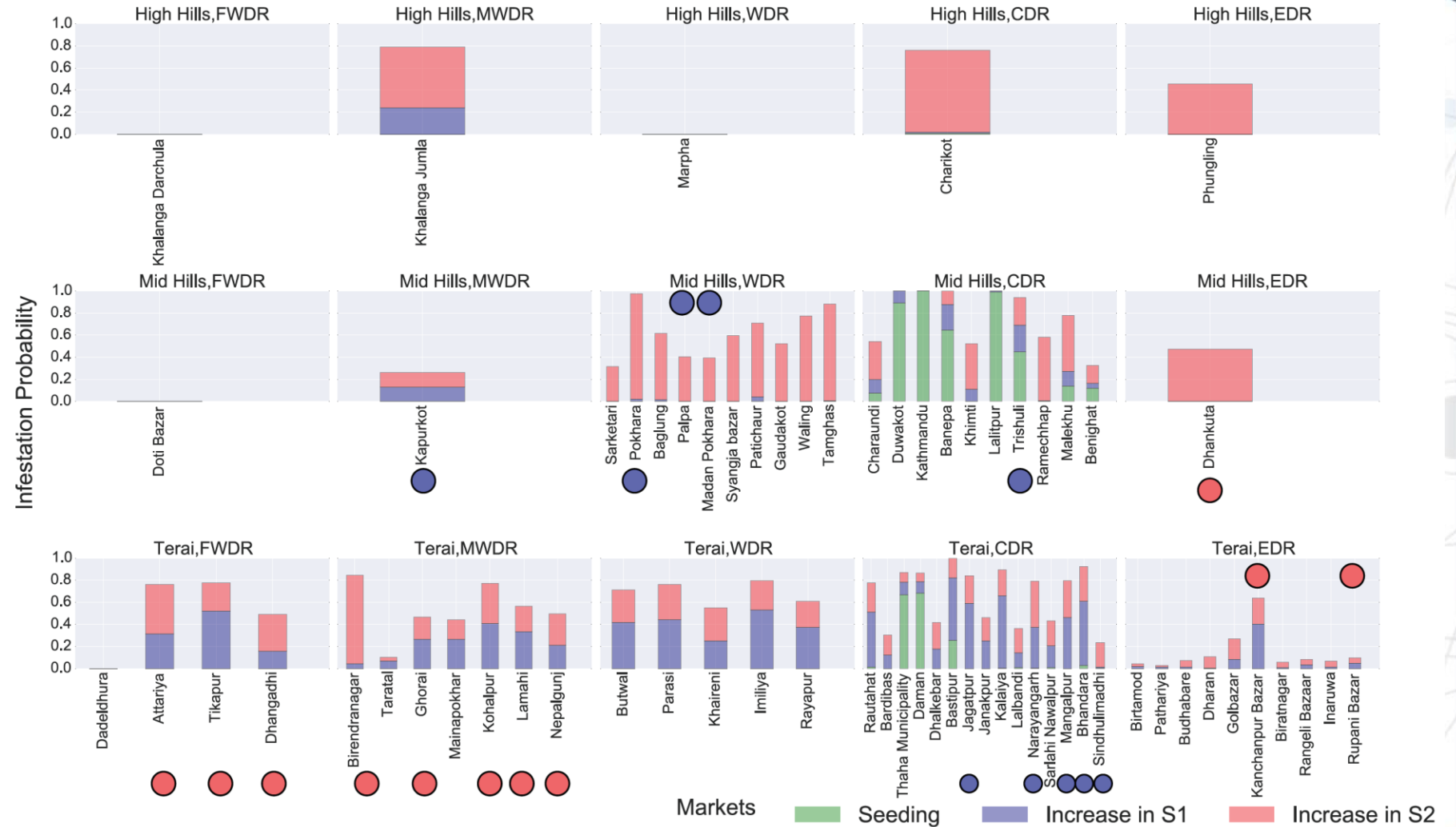
Forecasting



(a) Development regions

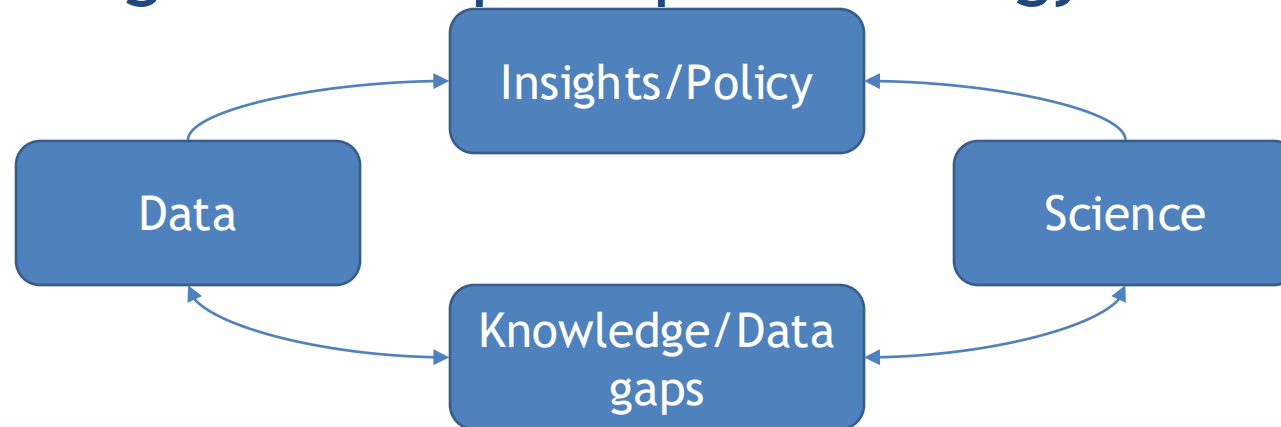


(e) Regions by altitude



What next?

- Provided economic impact assessments to USAID/Nepal
- Incorporating multi-year dynamics and intervention response
 - Pesticide use, Farmers' practices, National policies
- Model being used to assess spread risk in South-East Asia
 - Thailand, Laos, Cambodia, Vietnam
 - Identifying role of markets inform early surveillance
- Explicit integration of pest/plant biology



Beyond tomatoes & *Tuta*

- The proposed approach generalizes for other agro-products, and regions.
- International food flow models can be used to understand food sufficiency, price elasticity, food waste, etc.
- Can be used to assess disruption risk due to other phenomena
 - Biological attacks, droughts, natural disasters, wars, trade policies
- Mechanistic modeling approaches yield to ‘what-if’ analyses
 - Descriptive, hence explainable
 - Model quality improves with data
 - Data collection in turn informed by model

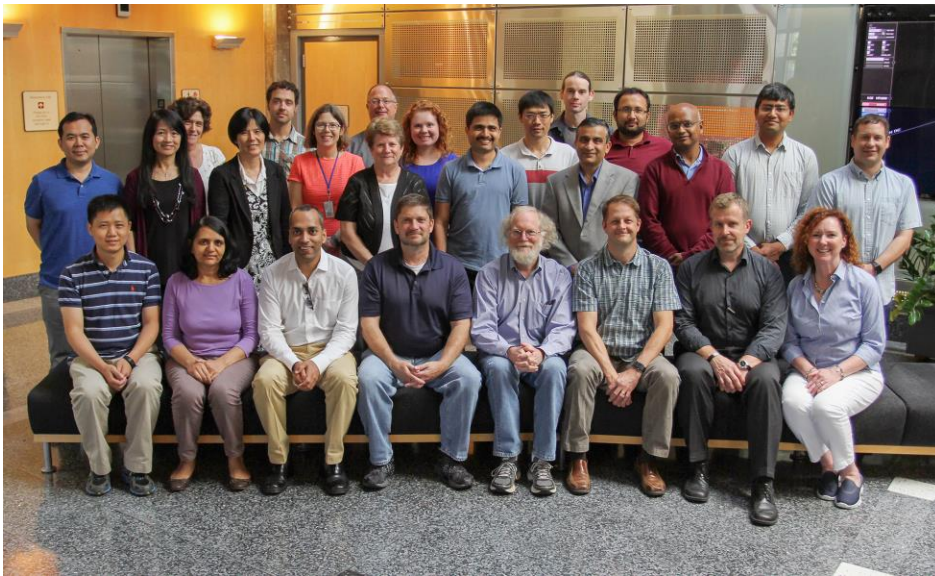
Acknowledgments



USAID
FROM THE AMERICAN PEOPLE



LA RECHERCHE AGRONOMIQUE
POUR LE DÉVELOPPEMENT



NDSSL, BI of VT



Tuta absoluta Symposium - Kathmandu'17

Questions?

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