Applying new tools in CLIMEX to explore parameter sensitivity, model uncertainty and inter-annual variation in climate suitability

The potential distribution of *Chilo partellus*, including the effects of irrigation

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August 2016

HEALTH & BIOSECURITY
www.csiro.au

Chilo partellus

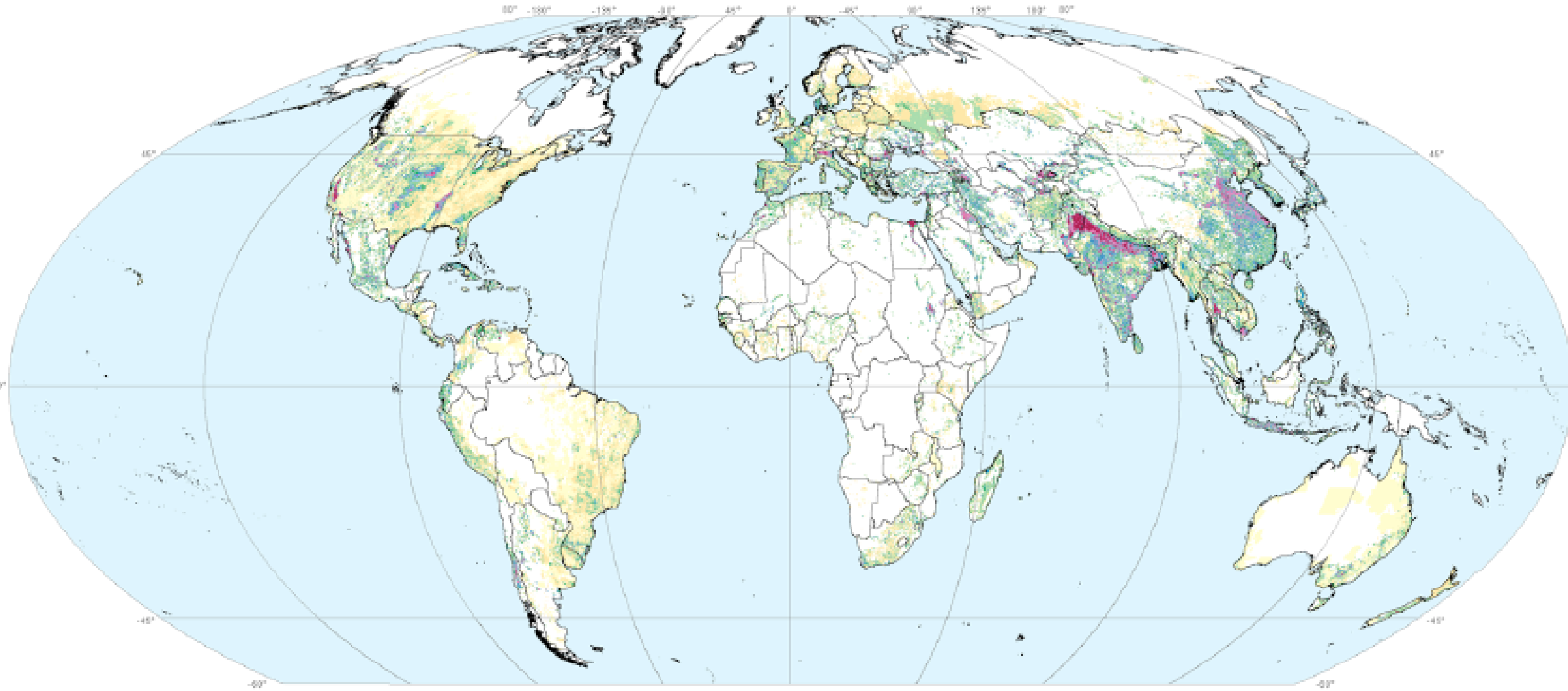
- Major crop pest
- Originally from Asia and Africa
- Recently spread to the Mediterranean region

Considering irrigation for crop pest niche modelling

- Many (perhaps most) agricultural crops are irrigated somewhere in their range
- The cardinal assumption in correlative species distribution modelling is that the species is at equilibrium with its environment
- The fine print…
  - The environment is represented by bioclim variables
  - The bioclim variables are built using ***natural rainfall*** climate variables
- What is the effect of building a model with distribution points collected from a mixture of irrigated and non-irrigated sites?
  - Model parameters are distorted, losing meaning and interpretability
  - Model skill is reduced, with *specificity* sacrificed in order to maintain *sensitivity*
    - All arid regions become suitable, even if they are not irrigated.

The digital global map of irrigation areas

February, 2007



Area under irrigation in percentage of land area

	0		10 - 20
	<0.1		20 - 35
	0.1 - 1		35 - 50
	1 - 5		50 - 75
	5 - 10		75 - 100

The map depicts the area equipped for irrigation in percentage of cell area.
For the majority of countries the base year of statistics is in the period 1997 - 2002.

Projection: Mollweide

http://www.fao.org/ag/agl/aglw/aquastat/irrigationmap/index.stm

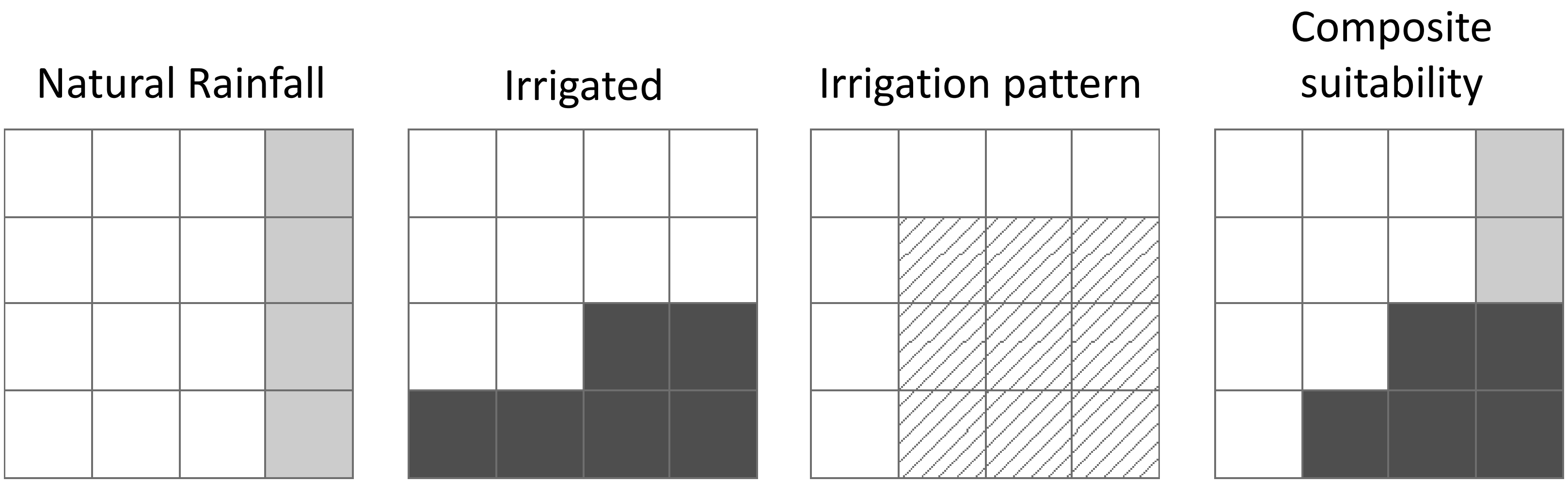
Stefan Siebert, Petra Döll, Sebastian Feick (Institute of Physical Geography, University of Frankfurt/M., Germany) and
Jippe Hoogeveen, Karen Frenken (Land and Water Development Division, Food and Agriculture Organization of the United Nations, Rome, Italy)

Including Irrigation in CLIMEX Niche Models

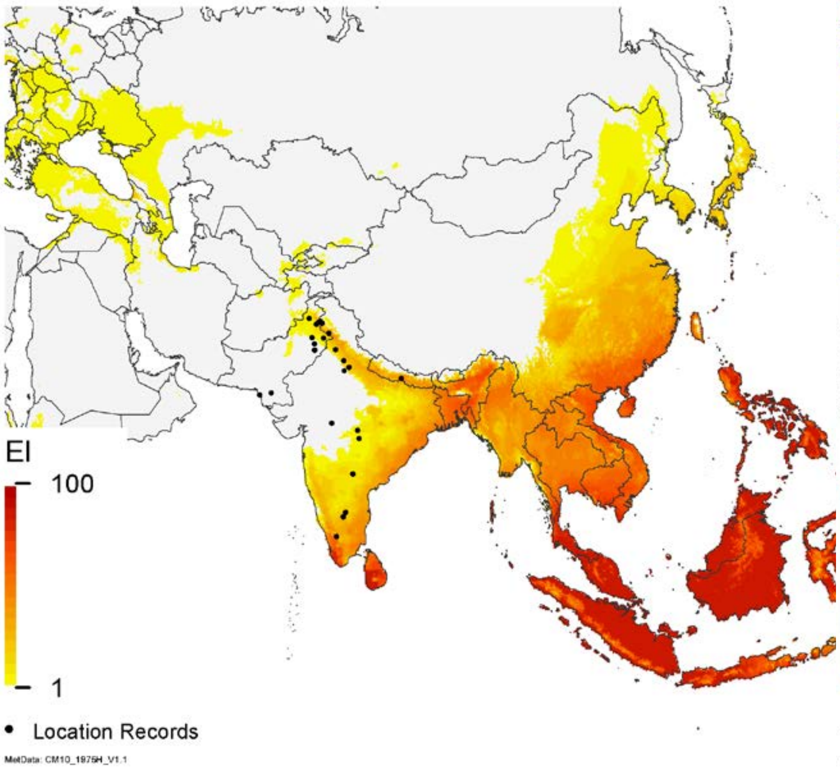
- Collate distribution data
- Fit initial soil moisture and temperature parameters using biologically reasonable values
- Assess fit
- Identify outlying points
- Explore using Google Earth or similar, identify evidence of irrigation
- Apply an irrigation scenario (2.5 mm day-1 of top-up irrigation is usually satisfactory)
- Combine results of irrigated and natural models using the GMIA dataset

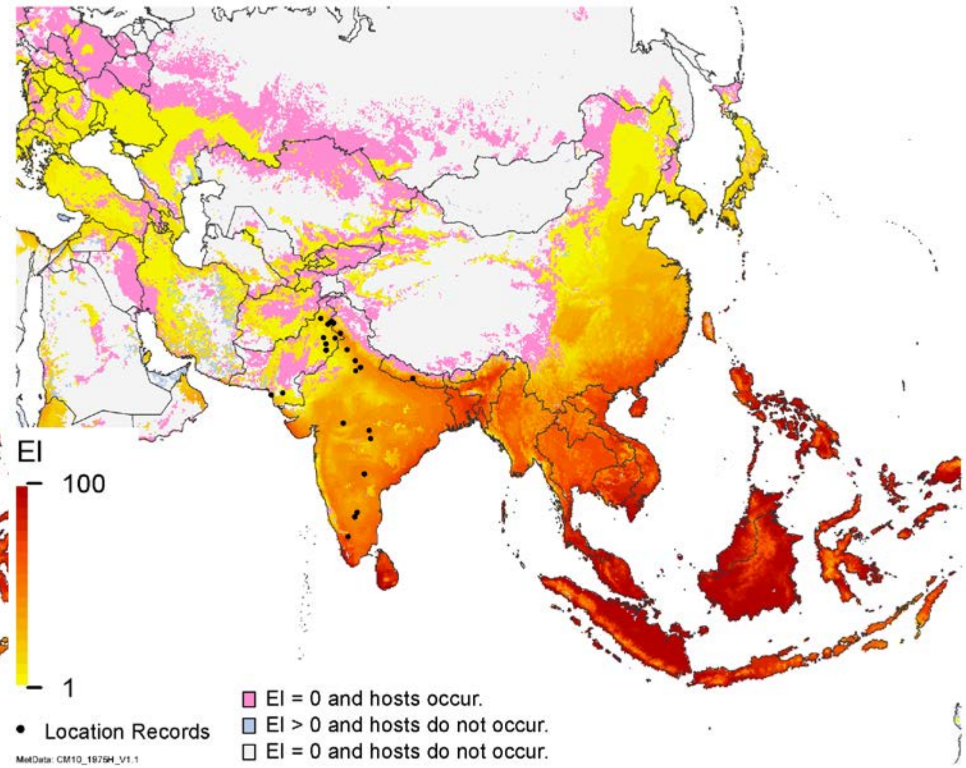
Composite niche maps

- Use spatial intersection to create a composite risk
- $\text{Risk}(Y) = \text{Max}(Y_I, Y_N \mid \text{irrigation})$
- If irrigation is present, then the risk is the highest value of the two scenarios, otherwise it is the natural rainfall value.

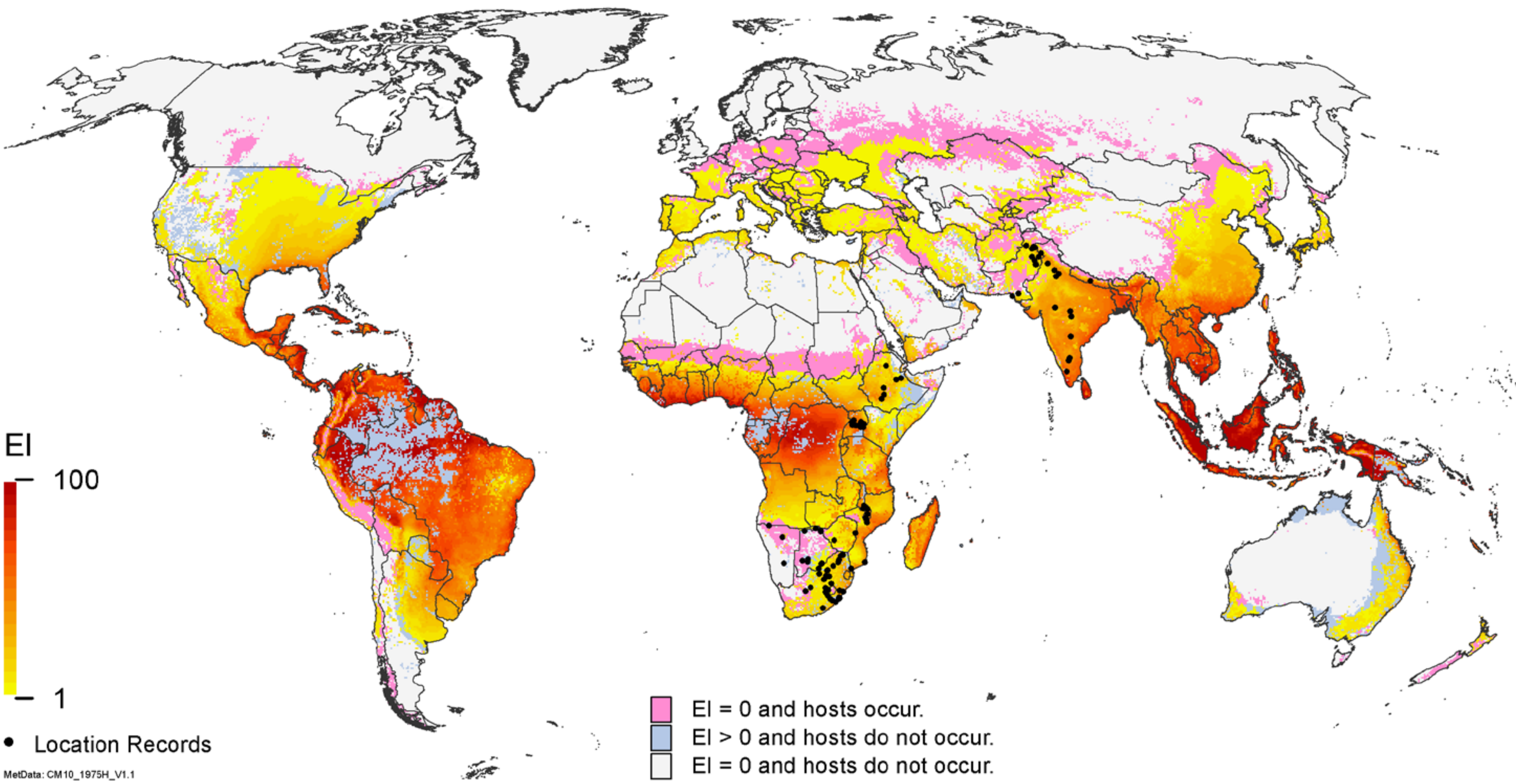


Chilo partellus potential persistence in Asia

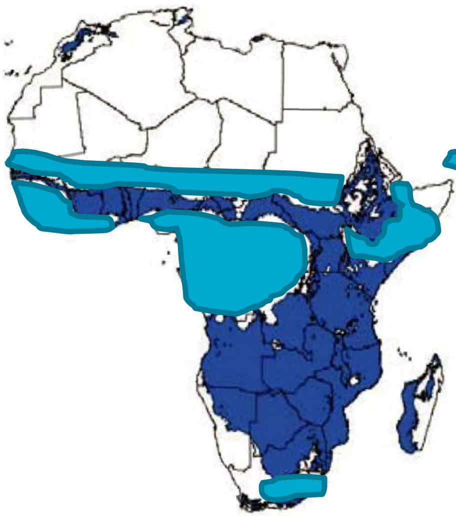




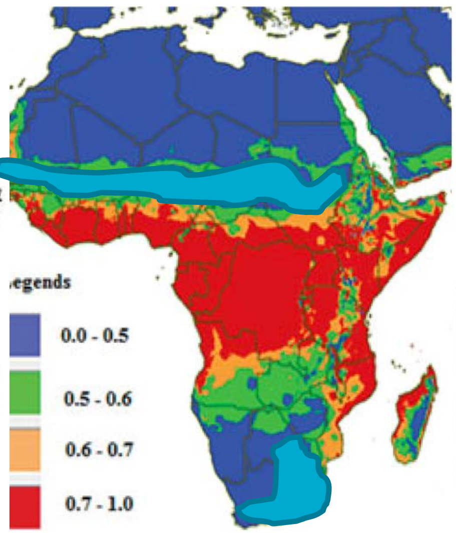
Global threat of *Chilo partellus*



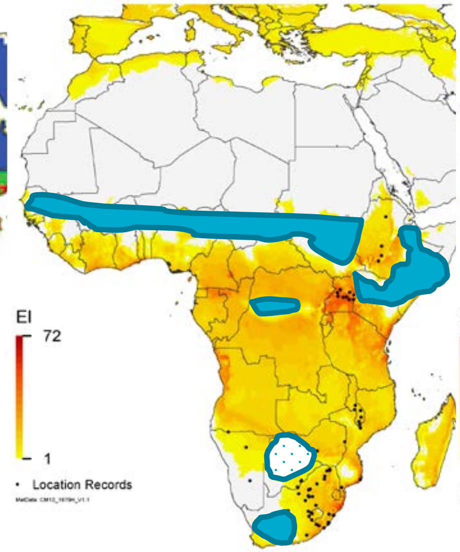
Results compared



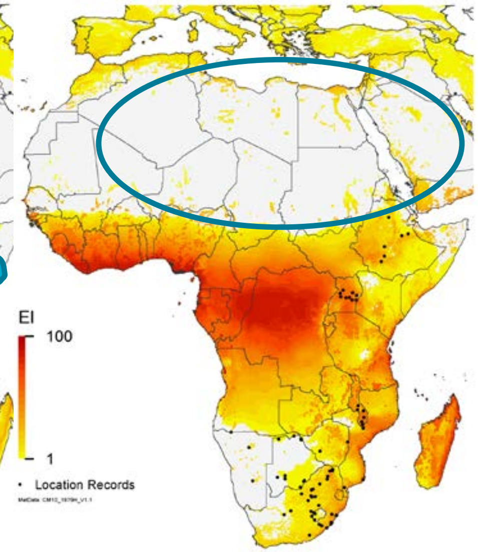
Overholt et al. 2000
Bespoke method



Khadioli et al. 2000
ILCYM



Hutchison et al. 2008
CLIMEX



Yonow et al. 2016
CLIMEX

Sensitivity and Uncertainty

- More frequent calls in the literature to undertake some form of uncertainty analysis
  - Venette et al. 2010 Roadmap paper
- CLIMEX Version 4 provides tools to automate the analyses

Sensitivity vs Uncertainty

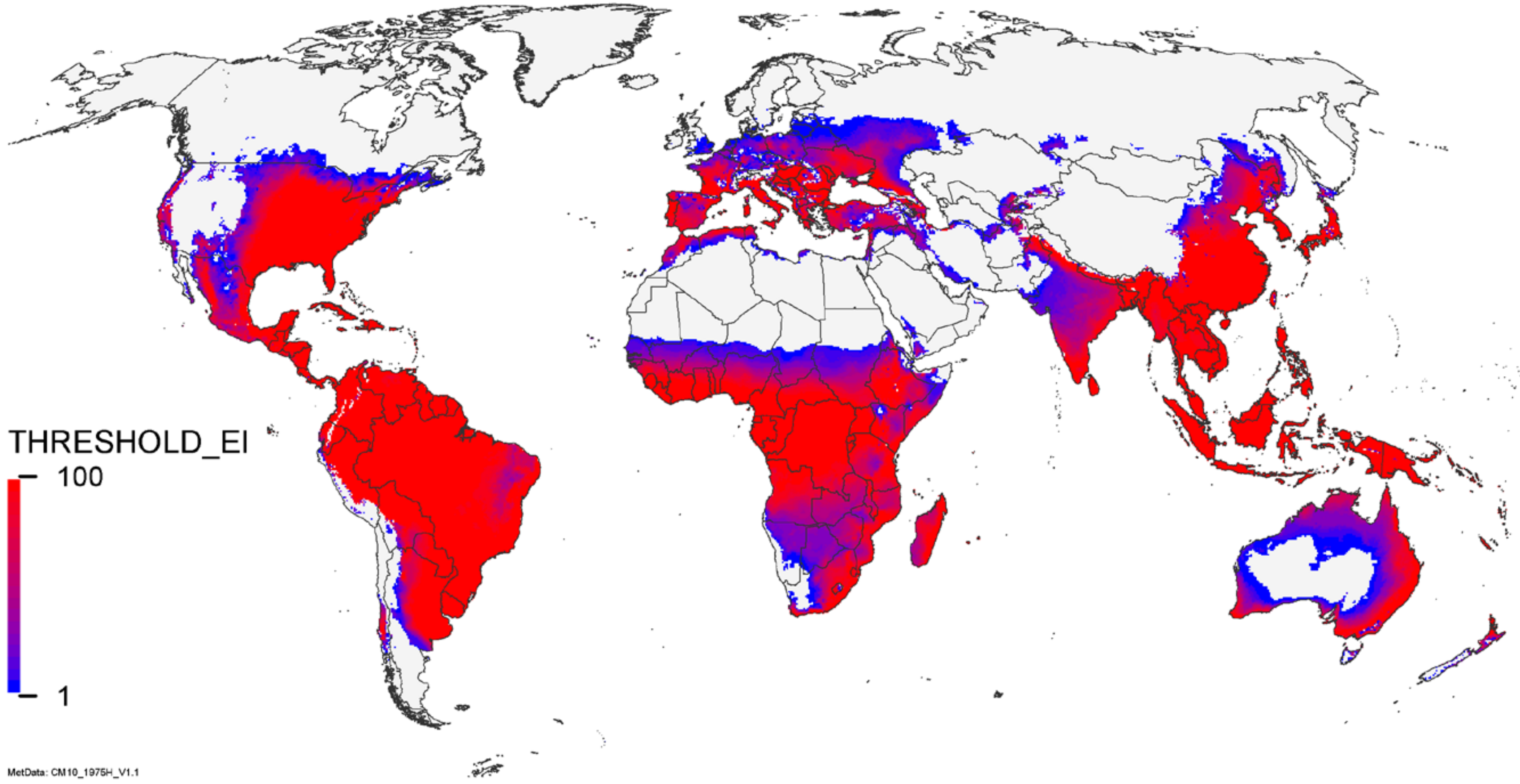
- Parameter sensitivity is the strength of the effect of each ***parameter*** on state variables
  - Adjust each parameter and assess change in state variables
  - Produces a table of sensitivity results
  - Identifies which variables we need to consider carefully
  - Sensitive variables that we are poorly confident about = high concern

- Uncertainty is an estimate of incertitude in the ***results*** of the model
  - Apply parametric uncertainty
  - Latin hyper-cube sampling
  - Produces an agreement map

Sensitivity analysis

Parameter	Mnemonic	Parameter Values			Range Change (%)	EI Change	Core Distribution Change (%)	Growth Variables			Stress Variables			
		Low	Default	High				MI Change	TI Change	GI Change	CS Change	DS Change	HS Change	WS Change
Dry Stress Threshold	SMDS	0	0.1	0.2	7.02	10.09	11.07	0	0	0	0	63.42	0	0
Limiting low moisture	SM0	0	0.1	0.2	2.23	2.11	0	11.09	0	2.9	0	0	0	0
Limiting low temperature	DV0	11	12	13	1.64	1.15	0	0	2.4	1.4	0	0	0	0
Degree-days per Generation	PDD	560	700	840	1.44	0.39	0	0	0	0	0	0	0	0
Dry Stress Rate	HDS	-0.042	-0.035	-0.028	1.19	1.82	0.12	0	0	0	0	8.47	0	0
Cold Stress Degree-day Rate	DHCS	-0.00012	-0.0001	-0.00008	0.79	0.79	0.04	0	0	0	11.47	0	0	0
Cold Stress Degree-day Threshold	DTCS	14	15	16	0.32	0.4	0.1	0	0	0	5.4	0	0	0
Lower optimal moisture	SM1	0.7	0.8	0.9	0.32	1.41	0	7	0	1.8	0	0	0	0
Lower optimal temperature	DV1	26	27	28	0.15	2.93	0	0	4.7	3.1	0	0	0	0
Upper optimal temperature	DV2	32	33	34	0.02	0.65	0	0	3.3	0.9	0	0	0	0
Heat Stress Temperature Threshold	TTHS	39	40	41	0.02	0.24	0	0	0	0	0	0	15.26	0
Limiting high temperature	DV3	39	40	41	0.01	0.13	0	0	2.5	0.2	0	0	0	0
Wet Stress Rate	HWS	0.008	0.01	0.012	0.01	0.15	0	0	0	0	0	0	0	0.6
Wet Stress Threshold	SMWS	2.4	2.5	2.6	0.01	0.25	0.03	0	0	0	0	0	0	0.8
Heat Stress Temperature Rate	THHS	0.008	0.01	0.012	0	0.03	0	0	0	0	0	0	3	0
Upper optimal moisture	SM2	1.9	2	2.1	0	0.49	0	0.6	0	0.5	0	0	0	0
Limiting high moisture	SM3	2.4	2.5	2.6	0	0.3	0	0.37	0	0.3	0	0	0	0

Uncertainty analysis



Cautions with Sensitivity and Uncertainty Analyses

- Both analyses depend on the regions in which the analyses are conducted
- Neither addresses other forms of uncertainty
  - Is the model appropriate?
- A model with low sensitivity and low uncertainty could be highly erroneous!

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Interannual variation in climate

- PLAY Movie Here

Conclusions

- All distribution points do not mean the same thing
  - Ephemeral
  - Reliant upon artificial conditions
- Considering irrigation explicitly has a substantial (positive) impact on the modelling process and the results
  - Better model “skill”
  - Parameters retain their meaning, increasing confidence in the model
- Sensitivity analyses direct attention to important considerations
- Uncertainty analyses of more use to decision-maker
  - Needs more research attention to better convey messages
- Static maps hide the degree of variability in species range boundaries

Grazie mille!

- **CSIRO**

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