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Climate change and agriculture:

Introduced uncertainty, analysis of the weather change scenarios, and characterization of impacts on soil

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Climate change data

- Sources of uncertainty
- Site-specific case study data
- ‘Correcting’ Regional level data for a specific site
- Impacts on land use model estimates
- Characterising the future scenarios
  - Impacts on soil, access etc..

Analysis of CC impacts

✓ Quantitative analysis of climate change impacts enforces considerable rigor on our thinking about effects

✓ The limitations are:

- potential interactions and agro-ecological effects are only partly or poorly quantified and often not incorporated in assessment models (changes in soils, pest prevalence, concentration of pollutants, …)
- climate scenarios are so uncertain that one should investigate a wide range of climate conditions, in order to identify climatic conditions that are particularly damaging
- applied to agriculture, the analysis might then identify actions that could be taken to reduce or eliminate possible damages, but we have only a vague idea of what agriculture may look like in the future
- there are likely to be things that happen that we neither foresee nor imagine

Climate scenarios

- ✓ A climate scenario is a coherent, internally consistent and plausible description of a possible state of the climate; a projection may serve as the raw material for a possible future state, in addition to baseline conditions (e.g. present-day conditions)

- ✓ The concept of uncertainty is implicit in the philosophy of climate scenario development:
  - ✓ future changes presents an unlimited number of plausible combinations of future conditions (emission rates, CO_2 concentrations, climate conditions, …)
  - ✓ researchers should exercise extreme caution when evaluating future estimates of changes in climate

Weather variables

- ✓ The variables most often required are air temperature, rainfall and solar radiation (relative humidity, wind speed may sometimes be needed)
- ✓ Important issues in the development of baseline data sets are their spatial and temporal resolution and uncertainties related to their accuracy
  - ➢ Temporal distribution of weather has significant impact on model estimates
- ✓ Different impact assessments require different types and resolutions of baseline climatological data: these can range from globally gridded baseline data sets at a monthly timescale to single site data at a daily (or sub-daily) timescale

CC & Crop modelling

- ✓ A set of climate scenarios is often adopted for the crop modelling work to reflect, as well as possible, the range of uncertainty in projections: time slices incorporating 10-year periods centred around 2030 and 2090 are examined
- ✓ Crop models provide an important means of integrating many different factors that affect crop yield over the season;
  - ✓ scaling-up results from detailed understanding of plant and crop response to climate and other environmental stresses to estimate yield changes for the whole farm can, however, present many difficulties
- ✓ The CO_2 fertilization effect will probably increase yields (whereas air temperature and precipitation effects can be both beneficial and detrimental), but the magnitude of the effects remain uncertain, as well as the quantitative outcome from models, because the incorporation of the multiple effects of CO_2 in models has been incomplete
- ✓ Models require calibration and validation against known / measured conditions in order to evaluate future projections

Crop model inputs

- ✓ Biophysical models are generally sensitive to errors occurring in the key weather, soil, crop and management inputs, therefore model results must be accompanied by critical examination of the source and nature of the data used

- ✓ Increasingly more effort is required in terms of input data collection for a model of an annual crop, for a model describing crop rotations, and for a model to analyze agricultural practices in the whole farm; at some point the effort required to gather input variables and parameters may no longer be feasible

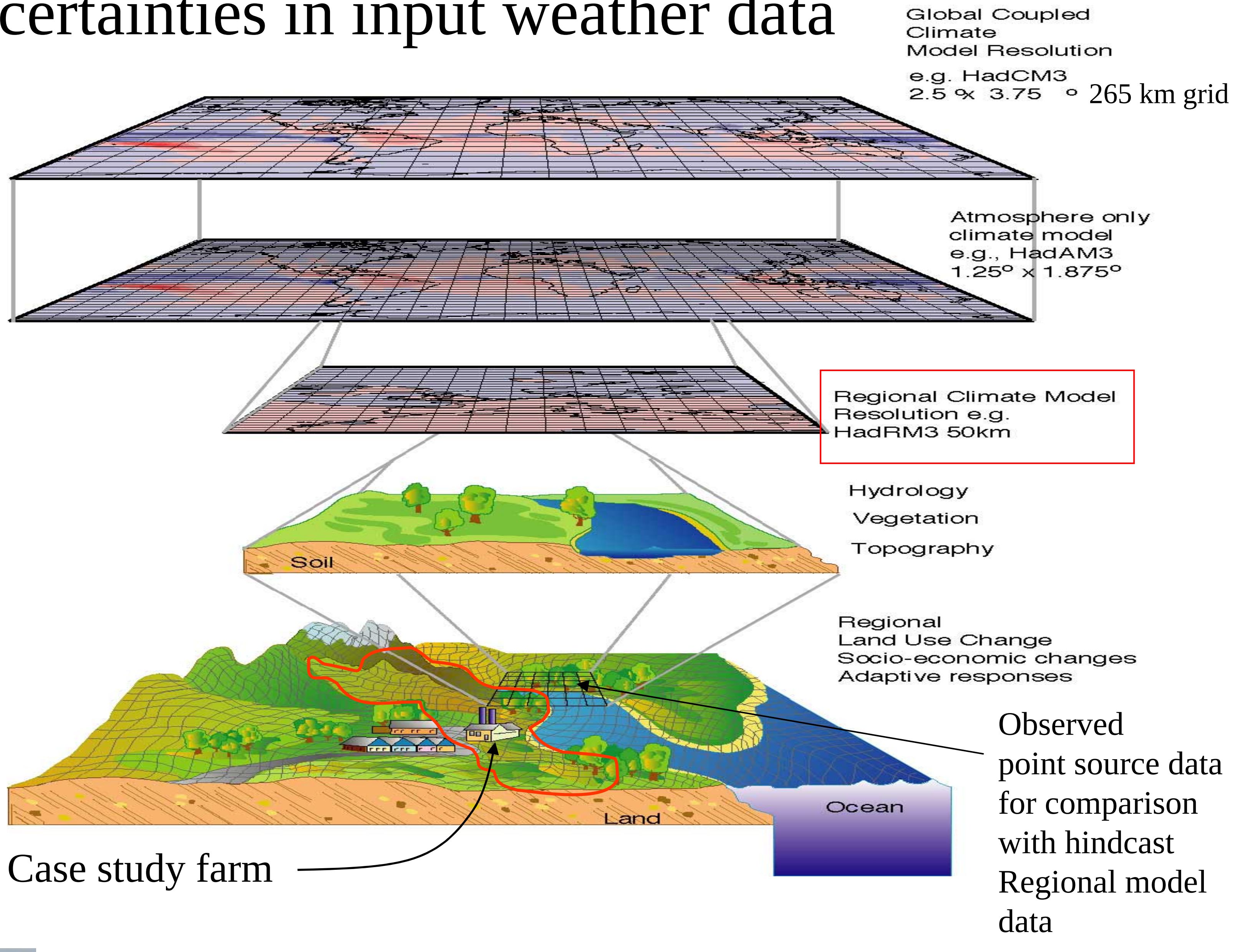
Weather inputs

- ✓ Common problems encountered with weather data are
  - ➢ records taken too far from the modelled site
  - ➢ errors under reporting values
  - ➢ poor maintenance and imperfect sensitivity of sensors
  - ➢ inconsistencies from weather data processing
    - • long series generation
    - • missing variables estimation
    - • grid-to-point downscaling

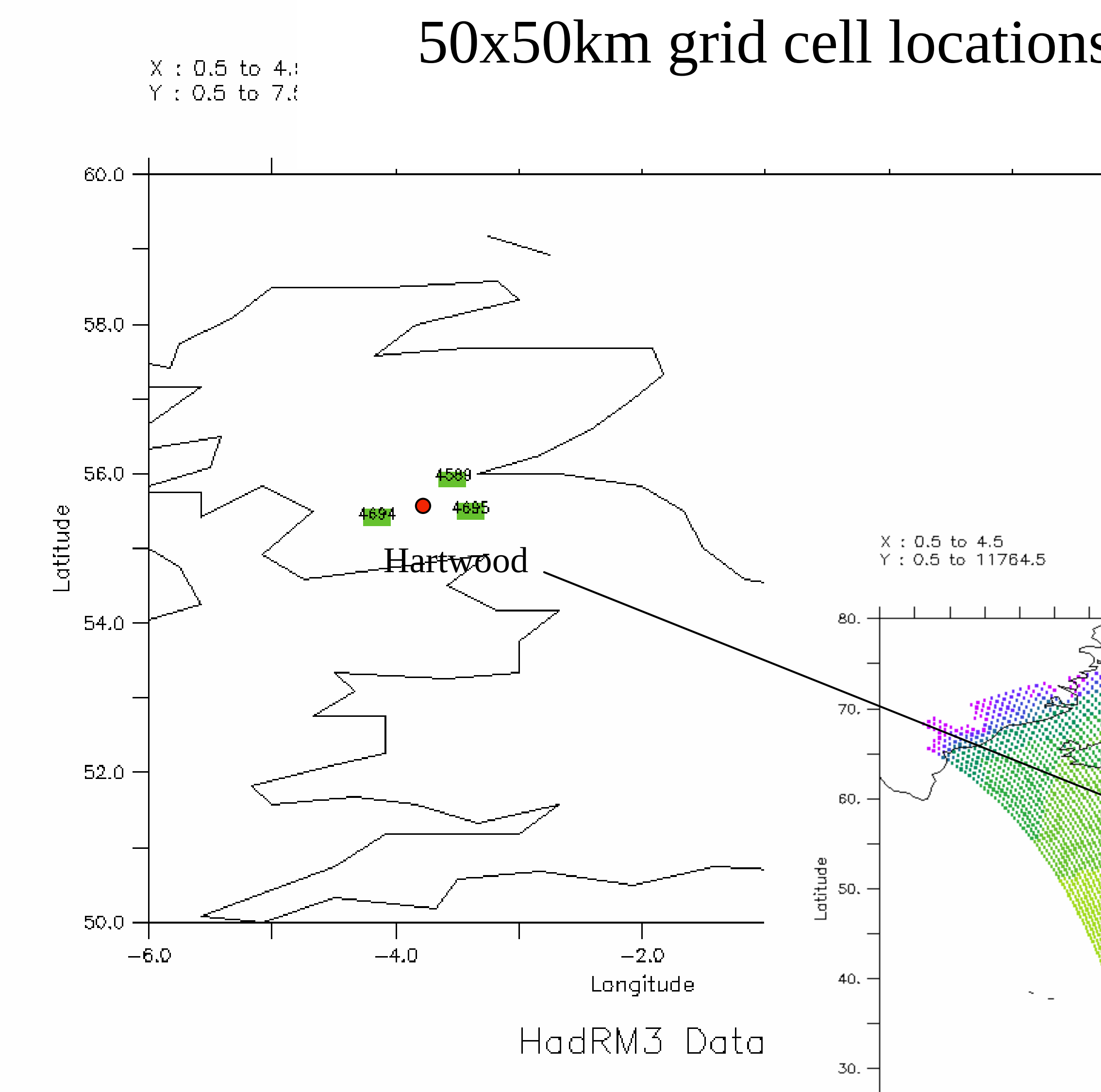
Hindcast runs

- ✓ Using high quality historical data is critical to generating a station-specific projection derived from the ensemble of gridded model outputs
- ✓ Typically, projection skill is evaluated by comparing how well the hindcasts performed (i.e. reconstructed weather data) compared against historical records
- ✓ The results from such tests provide a measure of confidence that the reconstructed data are robust and most appropriate for generating the station-specific projections from the gridded ensemble runs

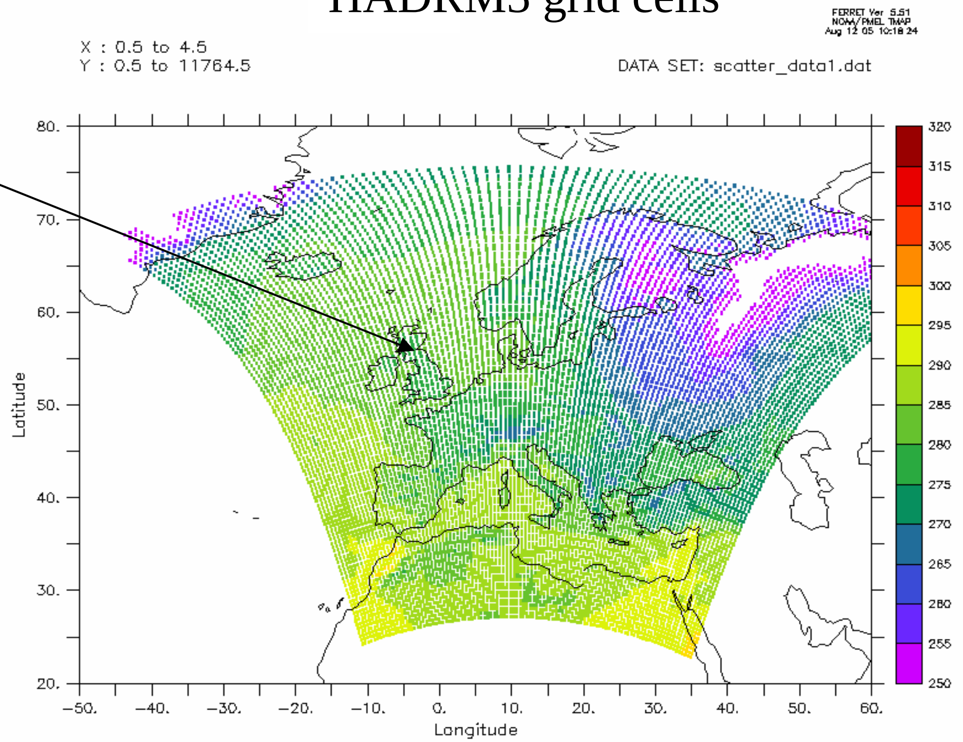
Uncertainties in input weather data



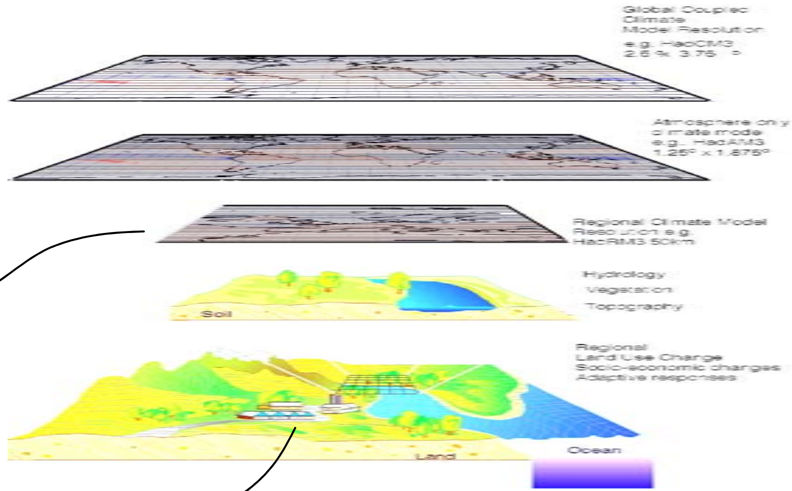
Which data source to use?
50x50km grid cell locations for Hartwood



HADRM3 grid cells



Climate change data analysis



Hadley Centre HADRM3
(50x50 km grid scale)

Hindcast
(1960-90)
Daily data

Observed point source data

Identify ‘site-specific differences’

Develop ‘correction factors’

Apply to future projections

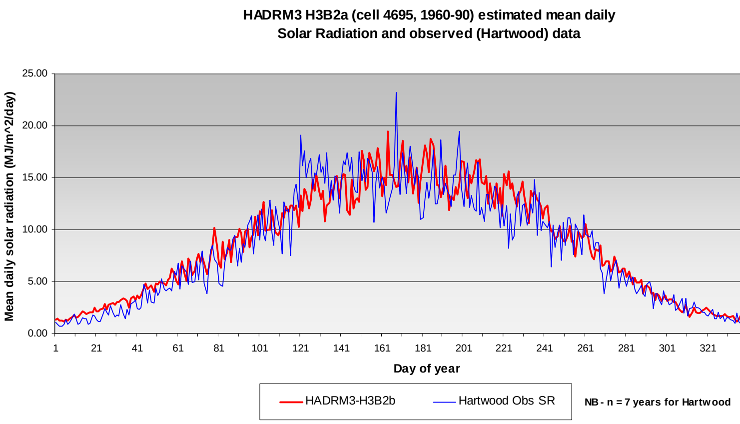
‘Corrected’ future projections

Future projections

‘Site-specific errors’ in modelled hindcast data
(1960-90)

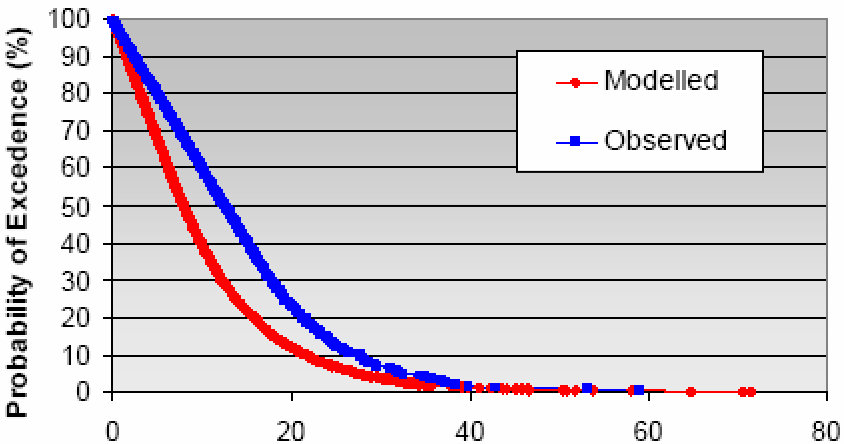
Comparison between site-specific observed and modelled data:

- Precipitation
  - Too many small estimated rain events
    - Mean of 132 observed no-rain days vs 50 modelled
  - Estimated annual totals too high
    - Observed mean of 817 mm vs 1036 mm modelled
- Temperature
  - Modelled mean Max temp too low by c. 1 degree C
  - Modelled mean Min temp too high by c. 1.8 degrees C
- Solar radiation
  - appears to be ‘reasonable’

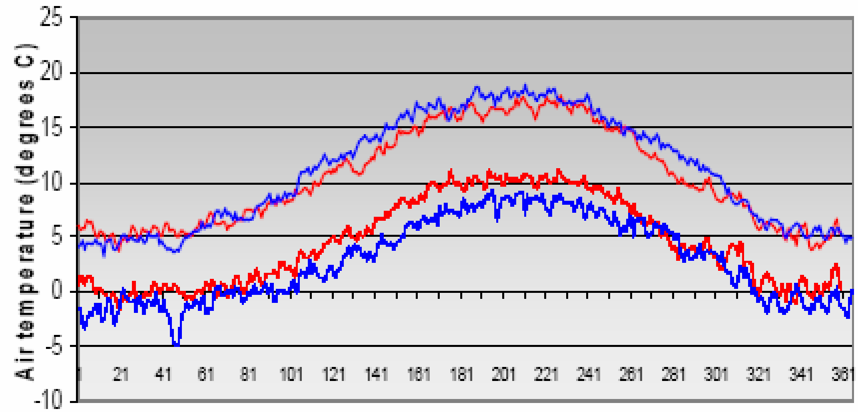


‘Correction’ factors applied to modelled hindcast data (1960-90)

Precipitation Event (>0mm) Probability of Excedence



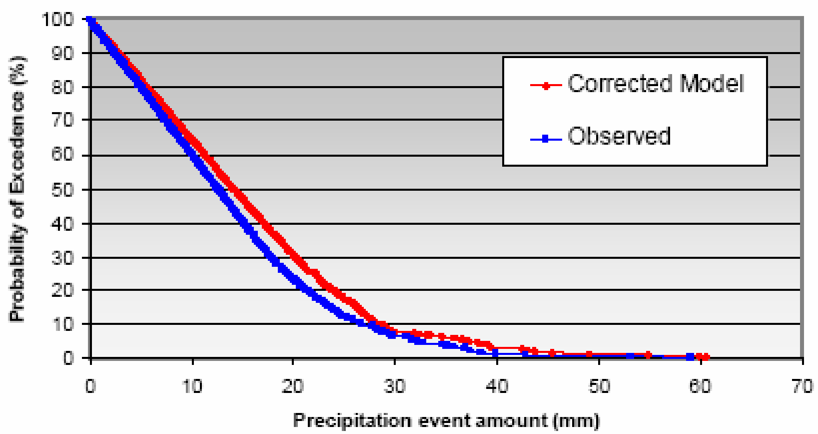
Maximum and minimum air temperature



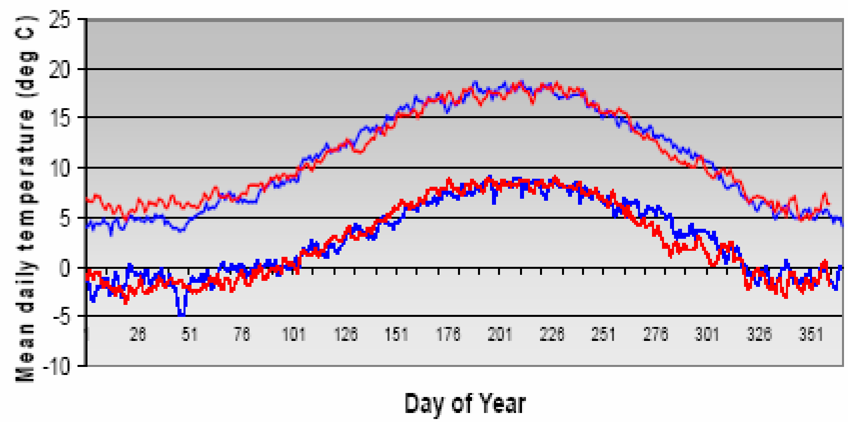
Correct for number of non-rain days and difference in mean annual totals, giving a difference of 4 non-rain days and 1.4mm mean annual total

Max temp - subtract an optimised value (negative) that gives 0 sum of mean daily differences over the growing season. Min Temp - Subtract an optimised value (positive) that gives 0 sum of mean daily differences.

Corrected Model precipitation Probability of Excedence



Corrected Maximum and Minimum Temperature



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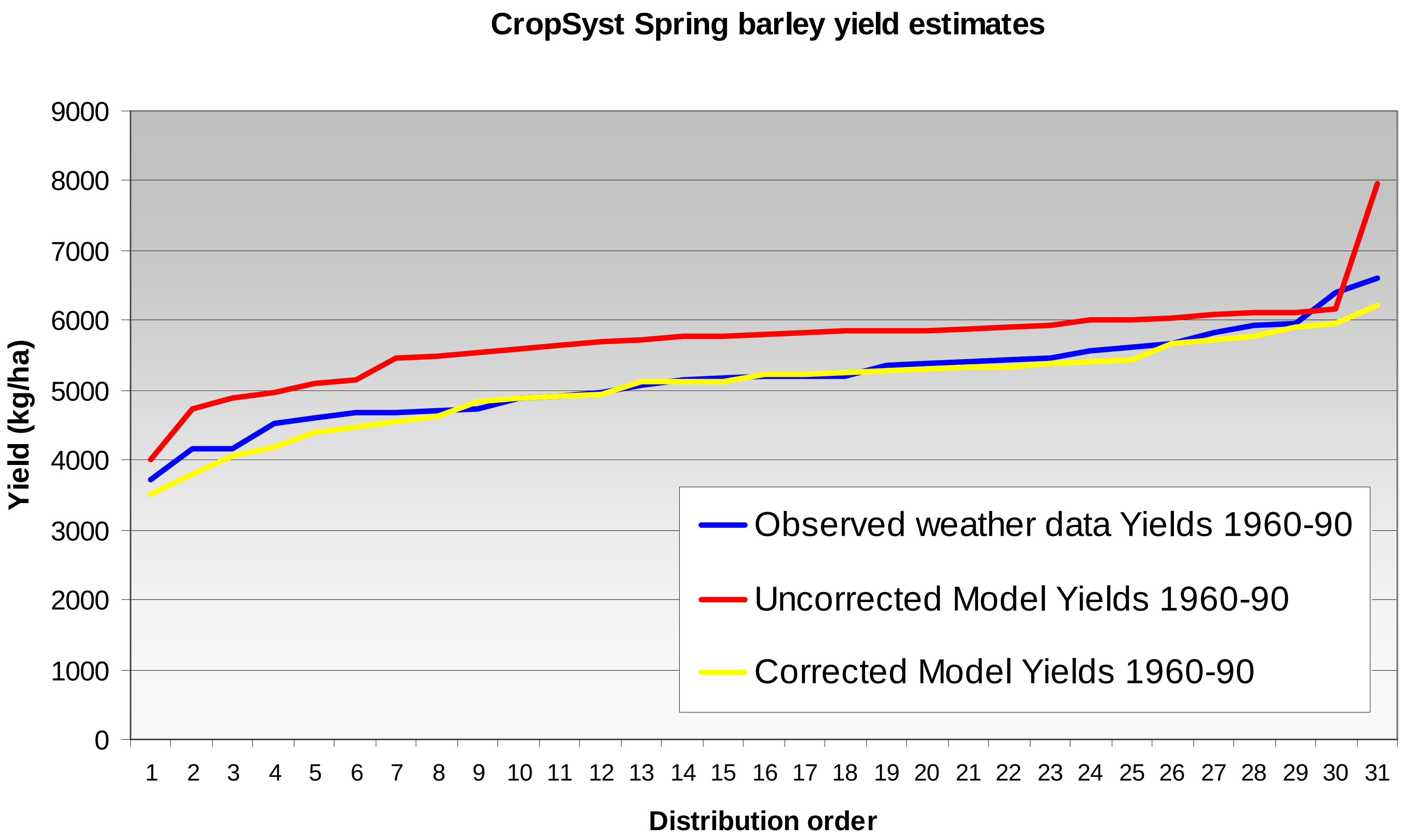
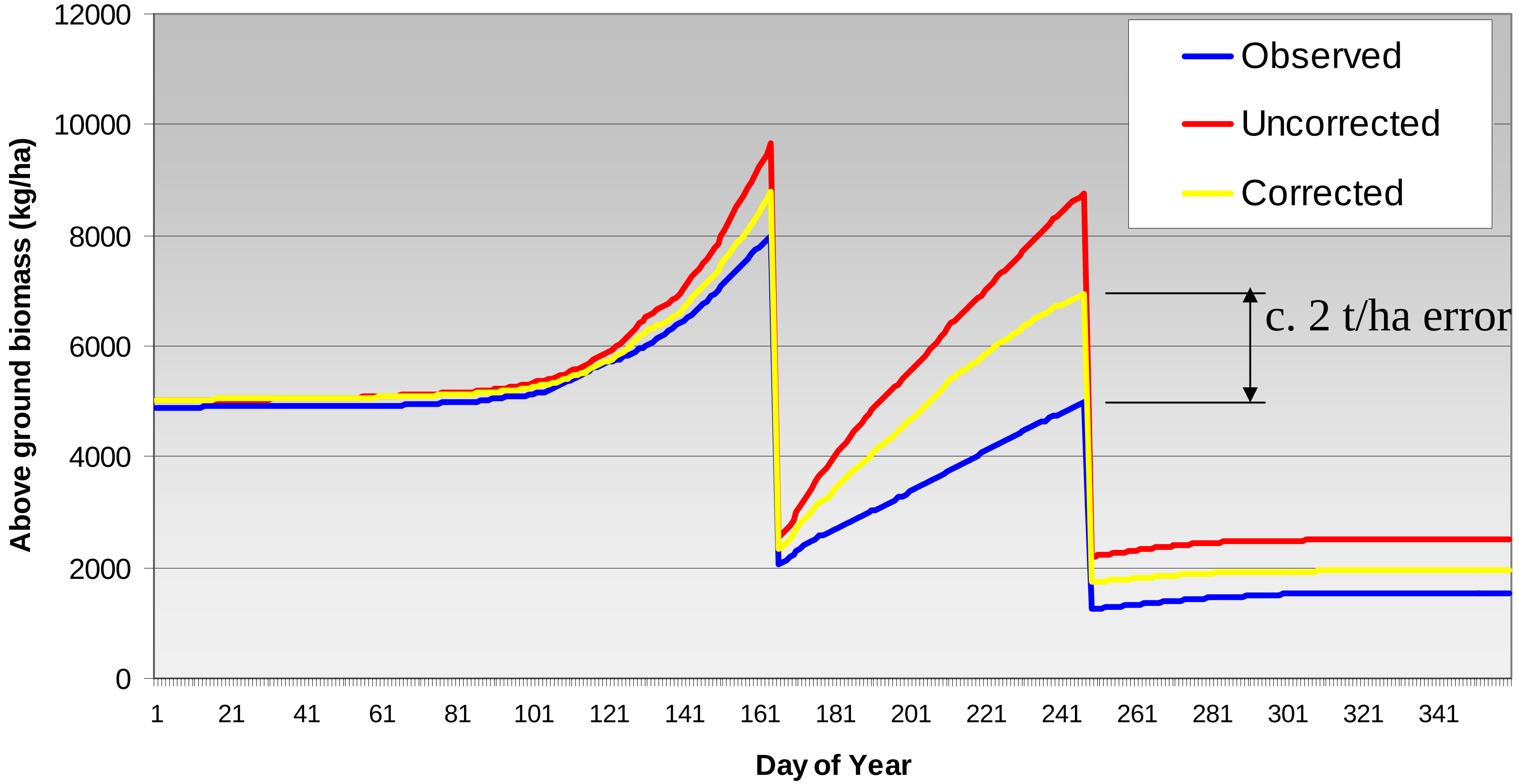
In assessing the introduced uncertainty to crop model estimates, applying the ‘correction’ factors to the weather data greatly improves the match between observed and estimated yields….



Introduced errors in a 2-cut silage system from climate data sources



Soil inputs

- ✓ Soil properties are essential inputs to models, but are often not direct field measurements, rather
  - ➢ soil survey reports
  - ➢ estimates from pedotransfer functions

- ✓ Fields are likely to be intrinsically heterogeneous, comprising a range of textures, with or without a spatial pattern; soil textures are often assumed to be homogeneous over a field (simulation unit) when they may vary by layer and field patch (inaccuracies are translated into the associated hydraulic properties)

- ✓ Crop models are often not very sensitive to soil inputs, but inaccuracies of both weather and soil inputs easily turn into combined effects, either able to strengthen or weaken each others' effect during model simulation

Crop parameters

- ✓ A complete calibration work (which requires reliable data being available) is often not at hand for whole-farm modelling studies, thus crop parameters are taken out of both literature and previous experiments (either conducted in the same region or country)

- ✓ Uncertainties in the parameters can turn into unpredictable errors propagating up to model outputs (errors are generally more effective under stressed conditions)

Crop management inputs

- ✓ Management inputs may only mimic at best the “mean” standard practices carried out at a farm site on each crop
- ✓ The amount and quality of management inputs may differ across crops, some practices being neither well documented nor well handled by models (e.g. fertigation)

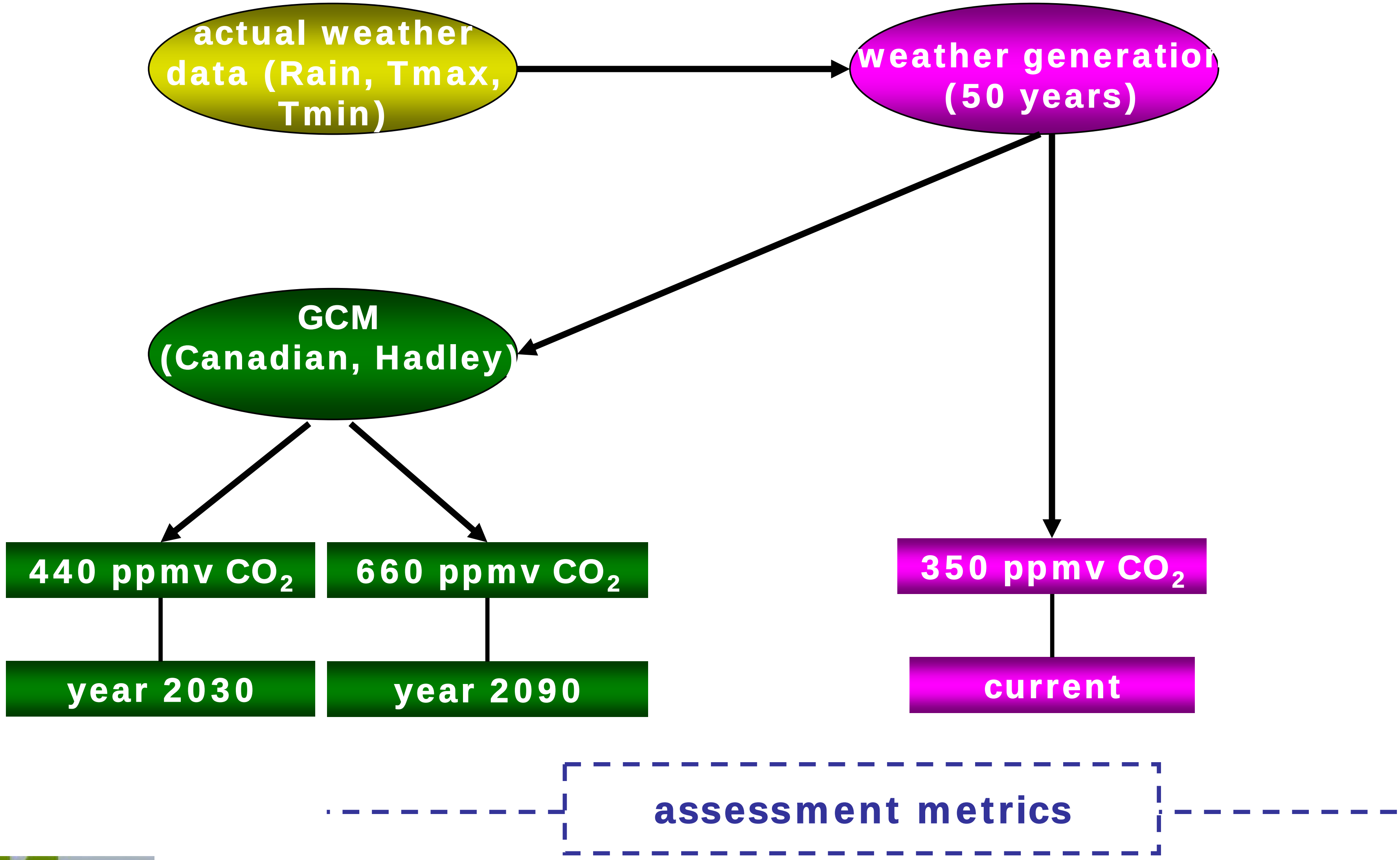
Remarks

- ✓ Detailed estimations of climate change impact studies are particular uncertain, but this must not become an excuse for impact assessments not to be done
- ✓ Projecting crop yield variability in the absence of climate change and comparing climate-induced changes to normal variability will help us understand the types of uncertainties that projected scenarios and crop models may introduce
- ✓ Even if the ability to assess the farming system in all its complexity does not yet exist, a sense of such studies being useful nonetheless remains because they force us to rethink fundamental relationships and interactions, consider broader connections, and conduct targeted research to investigate some of the links where little is known

Characterising climate change scenarios - Rationale

- ✓ Holistic studies of climate change impacts on whole farm systems require a range of assessment metrics to characterise the change scenarios
- ✓ Characterisation of the change scenarios is required to enable results from the overall holistic study to be put into context
- ✓ This will aid interpretation of output and subsequent development of adaptation and amelioration strategies

Methodology

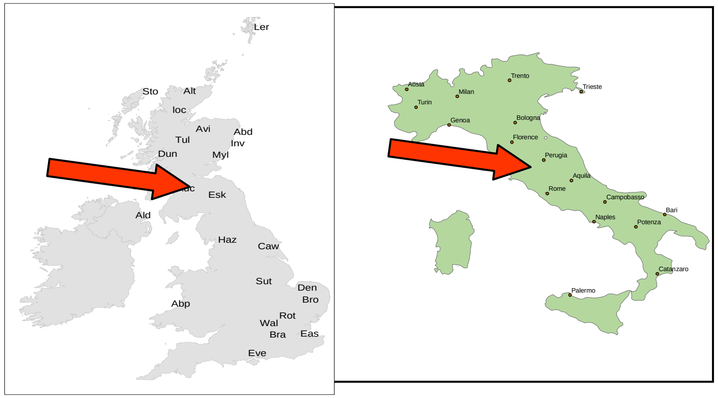


Climate Metrics

Basic weather variables

- ✓ rainfall (mm)
- ✓ air temperature (°C)
- ✓ evapotranspiration (mm d^{-1})

Hartwood Montepulciano

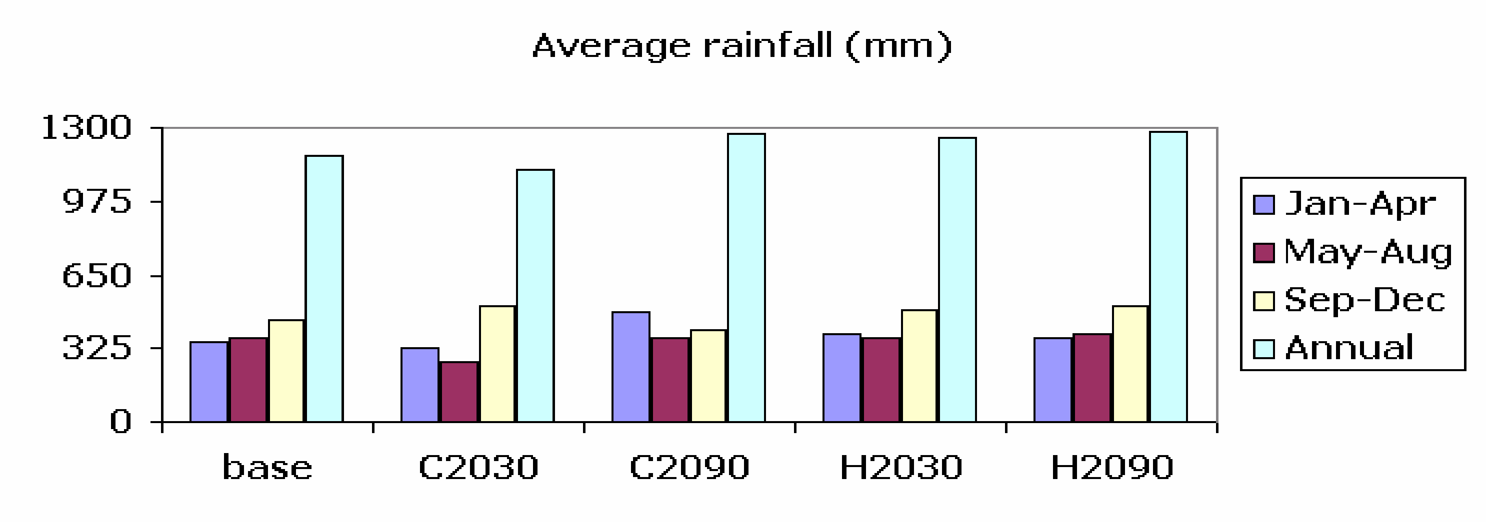


Derived weather variables / metrics

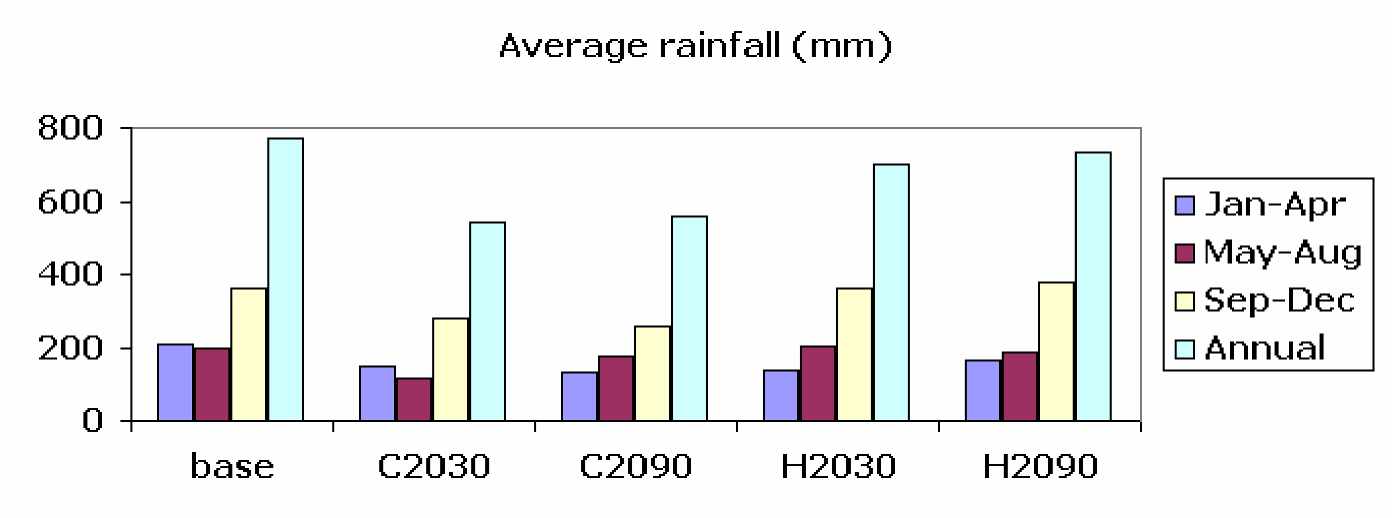
- ✓ rainfall seasonality index
- ✓ Fournier index
- ✓ ending field capacity (date)
- ✓ return to field capacity (date)
- ✓ access period (number of days)
- ✓ excess winter rainfall (mm)
- ✓ summer soil moisture deficit (maximum deficit, mm; air-dried soil, number of days)
- ✓ accumulated temperatures above 0 °C for January to June (°C-d)
- ✓ last spring air frost (date)
- ✓ mean air temperature above 5 °C (number of months)

Rainfall

Hartwood



Montepulciano



Rainfall seasonality index (number of years)

	current	C2030	C2090	H2030	H2090
	Hartwood				
>0.13 (wet season in summer)	5	0	0	5	6
<-0.13 (wet season in winter)	4	12	14	4	3
	Montepulciano				
>0.13 (wet season in summer)	9	11	14	17	14
<-0.13 (wet season in winter)	15	17	14	7	12

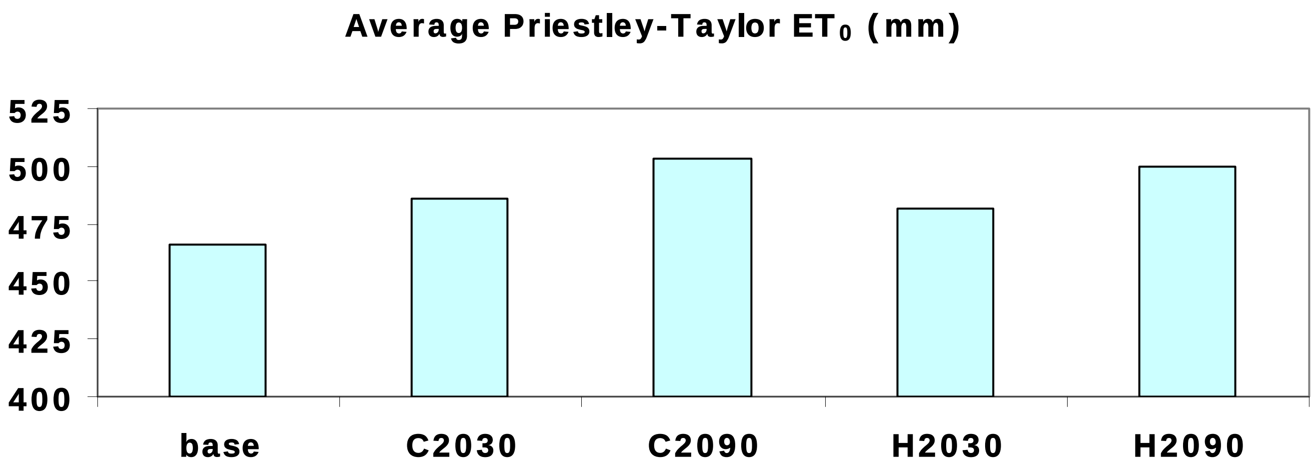
Fournier index

(number of years)

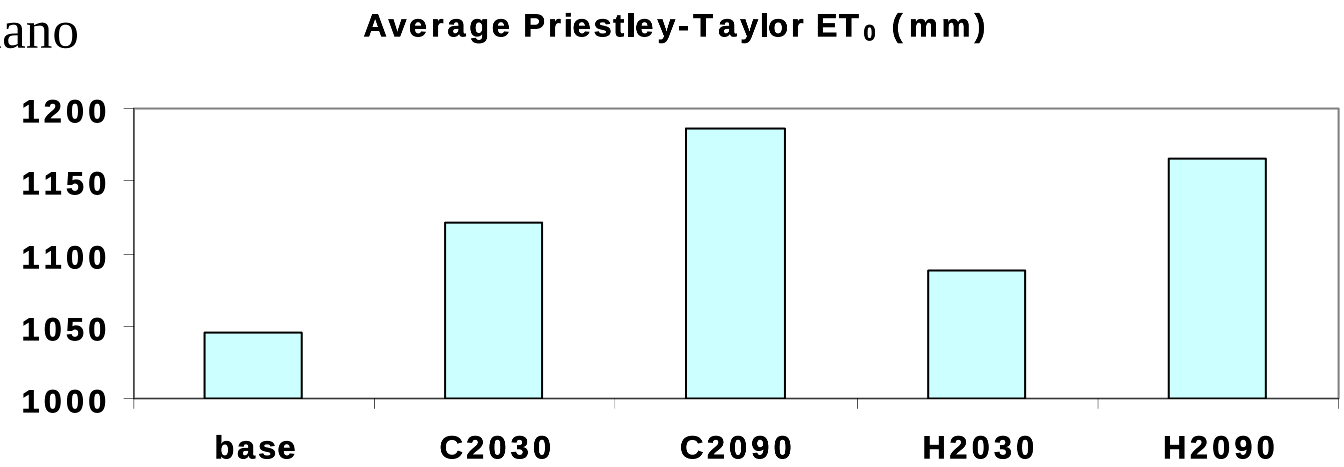
	current	C2030	C2090	H2030	H2090
			Hartwood		
<1300	19	16	7	9	6
1300-1800	31	32	40	41	41
1800-2200	0	2	3	0	3
2200-2500	0	0	0	0	0
2500-2700	0	0	0	0	0
>2700	0	0	0	0	0
			Montepulciano		
<1300	44	46	48	41	38
1300-1800	6	4	2	9	12
1800-2200	0	0	0	0	0
2200-2500	0	0	0	0	0
2500-2700	0	0	0	0	0
>2700	0	0	0	0	0

Evapotranspiration

Hartwood



Montepulciano



Summer Water Deficit

current	C2030	C2090	H2030	H2090
Hartwood (Max Soil Moisture Deficit, mm, median)				
85	48	60	82	76
Montepulciano (Air-Dried Soil, days)				
73	105	110	83	86

End of Field Capacity

(median day of year)

current	C2030	C2090	H2030	H2090
		Hartwood		
84 (late March)	86 (late March)	84 (late March)	84 (late March)	81 (late March)
		Montepulciano		
28 (late January)	1 (early January)	1 (early January)	14 (mid January)	15 (mid January)

Return to Field Capacity

(median day of year)

current	C2030	C2090	H2030	H2090
		Hartwood		
272 (late September)	277 (early October)	277 (early October)	273 (late September)	273 (late September)
		Montepulciano		
330 (late November)	343 (mid December)	346 (mid December)	334 (late November)	329 (late November)

Access Period
(median number of days)

current	C2030	C2090	H2030	H2090
		Hartwood		
185	188	193	185	188
		Montepulciano		
318	346	365	332	326

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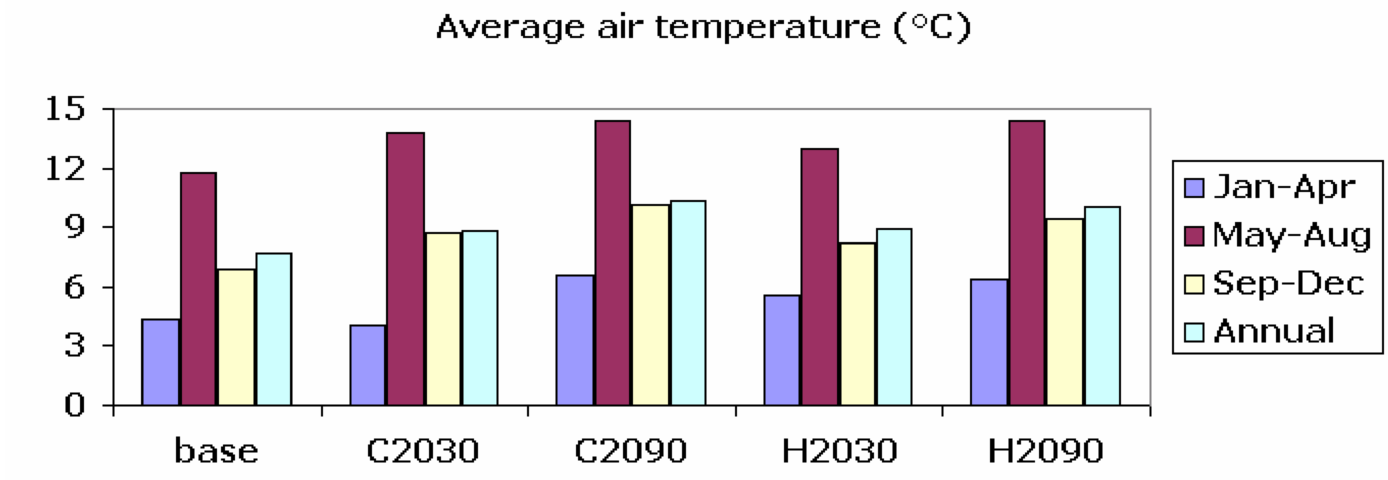
Excess winter rainfall
(mm, median)

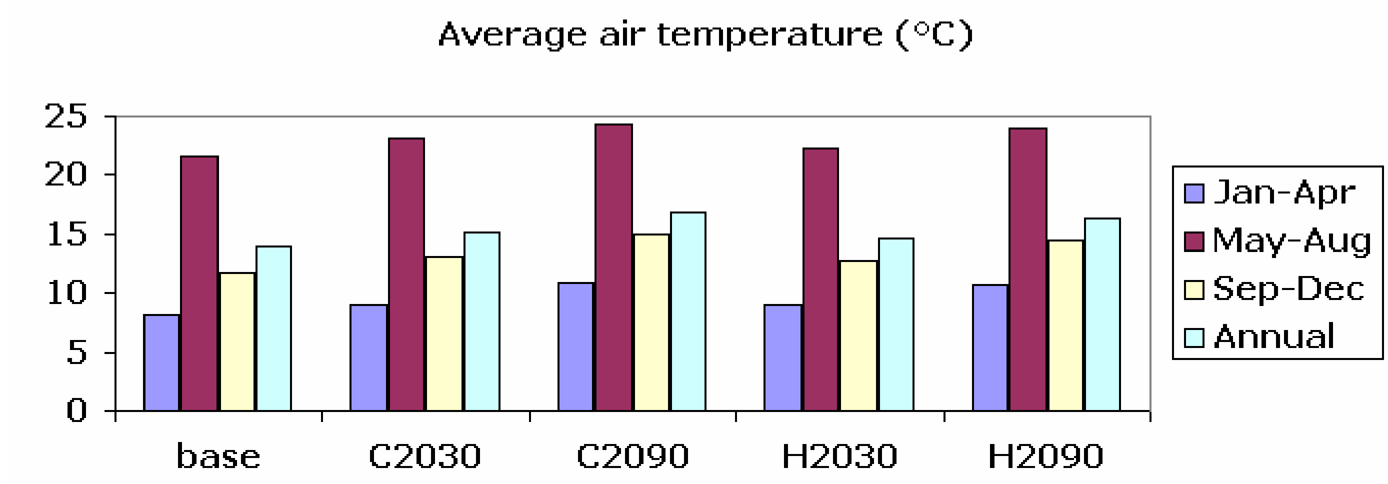
current	C2030	C2090	H2030	H2090
Hartwood				
564	537	581	600	628
Montepulciano				
77	0	0	35	45

Air Temperature

Hartwood



Montepulciano



Late Spring Air Frost
(median day of year)

current	C2030	C2090	H2030	H2090
		Hartwood		
130 (early May)	119 (late April)	116 (late April)	119 (late April)	112 (late April)
		Montepulciano		
30 (late January)	0 (early January)	0 (early January)	3 (early January)	0 (early January)

Accumulated temperatures above 0 °C January-June (°C-days, median)

current	C2030	C2090	H2030	H2090
		Hartwood		
1149	1197	1503	1350	1519
		Montepulciano		
2143	2318	2632	2289	2576

Mean air temperature > 5 °
(number of months)

current	C2030	C2090	H2030	H2090
Hartwood				
8	8	11	10	11
Montepulciano				
11	12	12	12	12

Remarks

✓ The results demonstrate the need to characterize climate change scenarios as part of holistic whole farm impact studies

✓ Warmer, wetter conditions in Scotland may favour land use production, whilst in Italy water stress may limit some land uses

✓ Access to land at Hartwood appears not to be an issue; there will be an increased irrigation requirement for Montepulciano