COSMOS-UK: A New Field-scale National Soil Moisture Measurement Network

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COSMOS India Workshop

12th - 13th June 2017, IISc Bengaluru, India

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Introduction

- COSMOS-UK Station Sensors
- How COSMOS works
- Correction of Neutron Counts
- COSMOS Footprint
- Comparison with point SM sensors
- Comparison with land surface models (JULES) and Remote Sensing SM products ASCAT and SCATSAR

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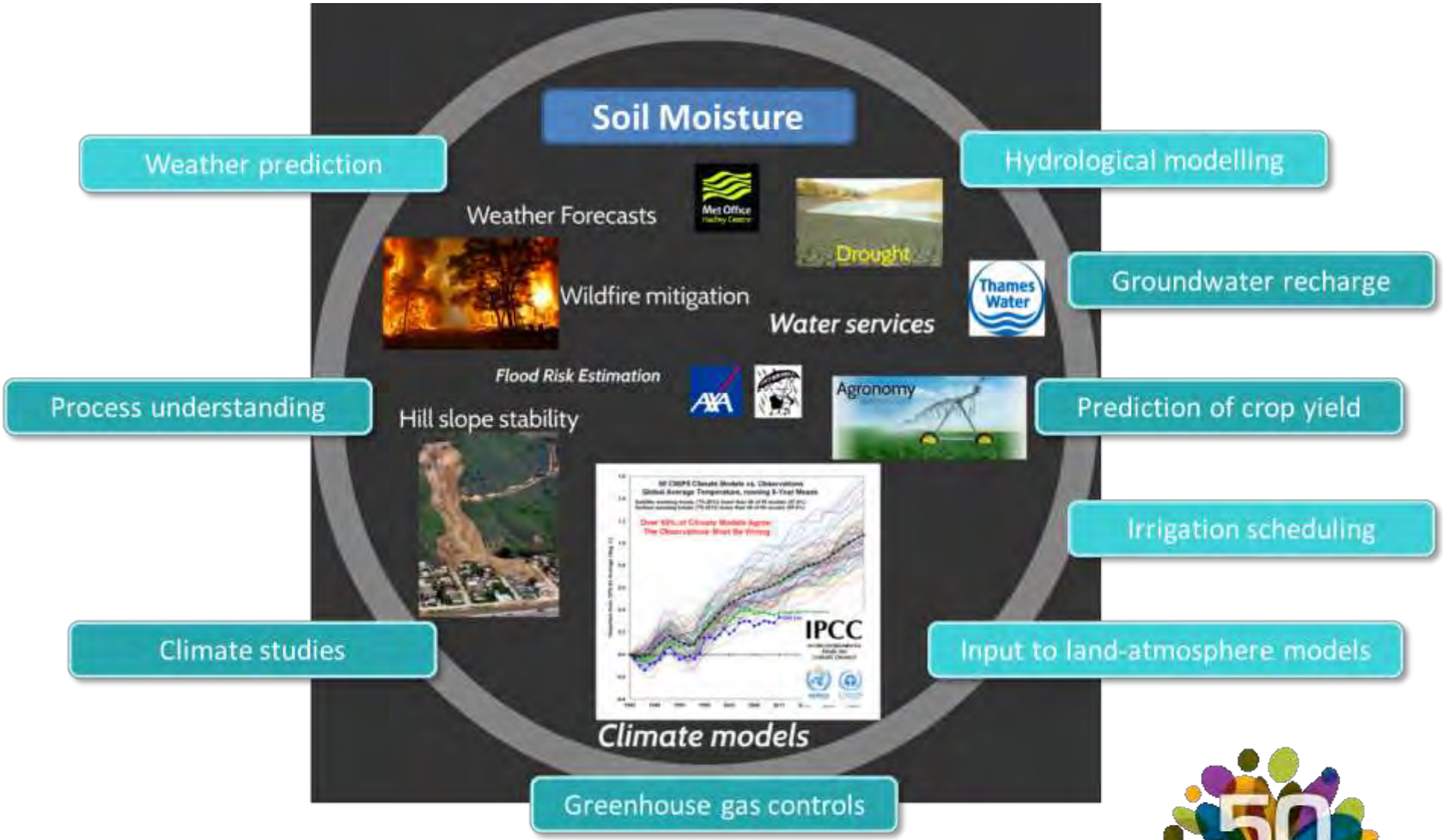
Scientific Rationale



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Point sensor to field scale SM: COSMOS

Acclima Time Domain Transmissometry (TDT) point soil moisture sensor (bottom left) & Soil heat flux plate (top right)

Cosmic Ray soil moisture Sensor (CRS) or 'COSMOS' Probe – field scale measurement

<u>Above</u>: Phenocam photo from Berambadi Eddy Covariance flux tower & COSMOS site, Karnataka, India
<u>Shows COSMOS 'footprint' or measurement area</u>

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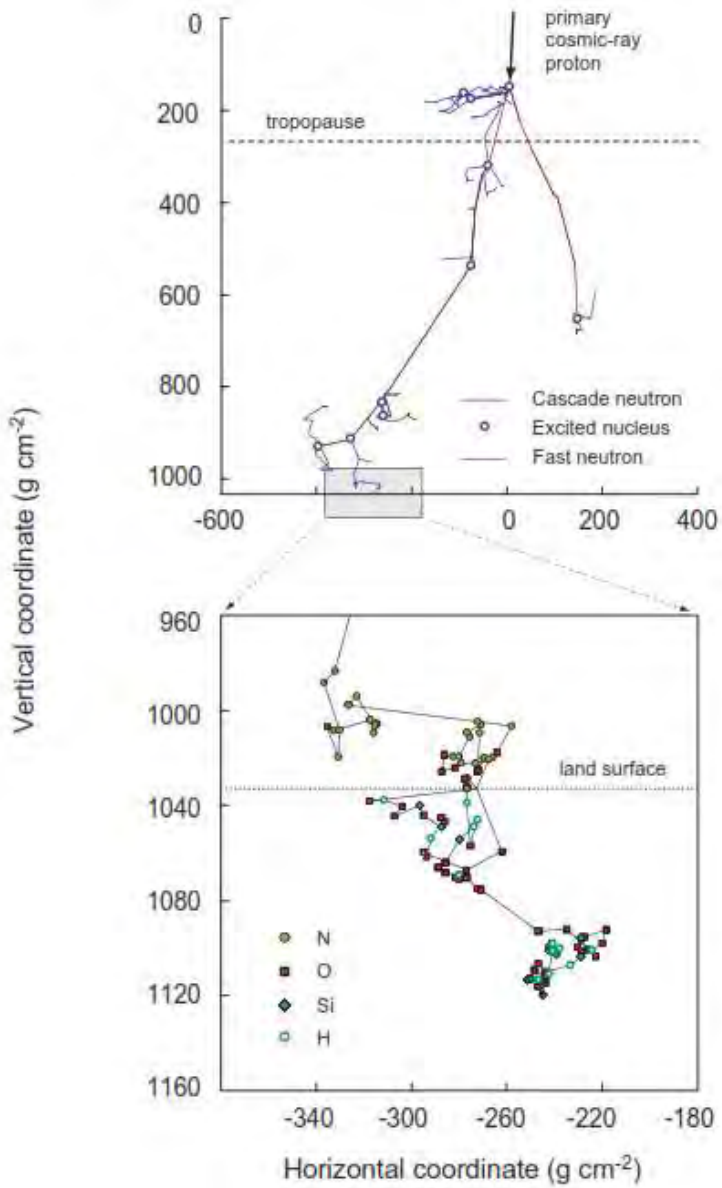
Cosmic Rays and Soil Moisture



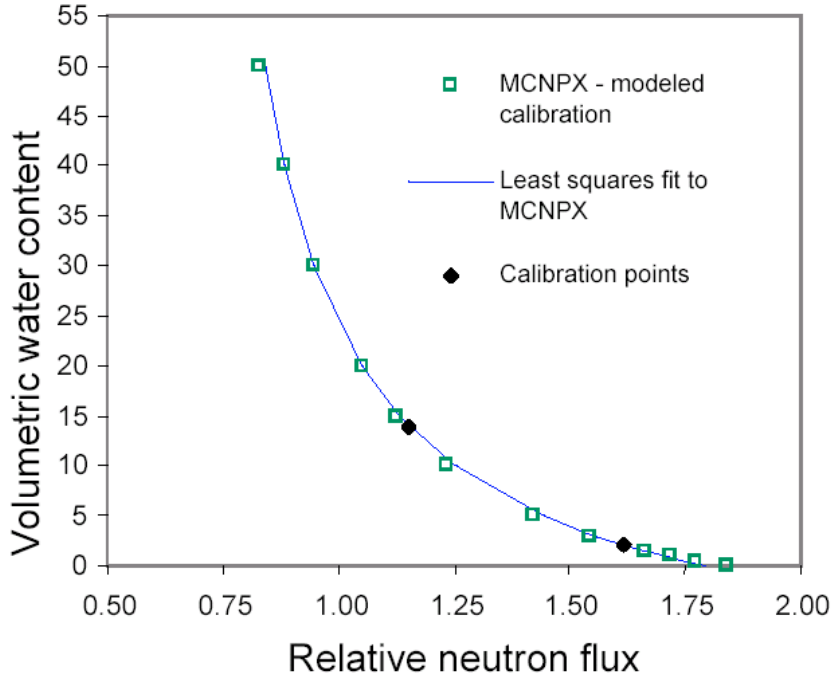
(1) A cascade of high-energy (~1 GeV) secondary neutrons are produced by primary cosmic ray protons entering the earth's magnetosphere

(2) High-energy secondary neutrons collide with nuclei in the atmosphere 'evaporating' fast neutrons (~1MeV) – these are scattered in the air and ground, loosing energy to become thermal (0.025 eV) or epithermal neutrons (> 0.5 eV)

From Zreda et. al.
Hydrol. Earth Syst. Sci., 16, 4079–4099, 2012
www.hydrol-earth-syst-sci.net/16/4079/2012/
doi:10.5194/hess-16-4079-2012

The COsmic-ray Soil Moisture Observing System

- Naturally occurring high energy neutrons generated by cosmic rays, are at equilibrium above the surface: the balance of supply of fast neutrons and their moderation (thermalisation) by surrounding nuclei.
- BF_3 or He^3 gas discharge tube (a.k.a. cosmic ray soil moisture probe) detects reduction in fast neutrons as soil moisture increases (more H).



Cosmic Ray Soil Moisture Probe (Hydroinnova CRS-2000/B) at Hollin Hill, N. Yorks.

Courtesy of: Marek Zreda, Jim Shuttleworth, Xubin Zeng, Chris Zweck and Ty Ferre

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Correction of Neutron Counts

SM is calculated from CRS counts after ***absolutely essential correction of neutron counts for***:

1) *Changes in Air Pressure*
2) *Variations in the intensity of incoming cosmic ray generated fast neutrons.*
3) *Changes in atmospheric water vapour (Relative Humidity)*

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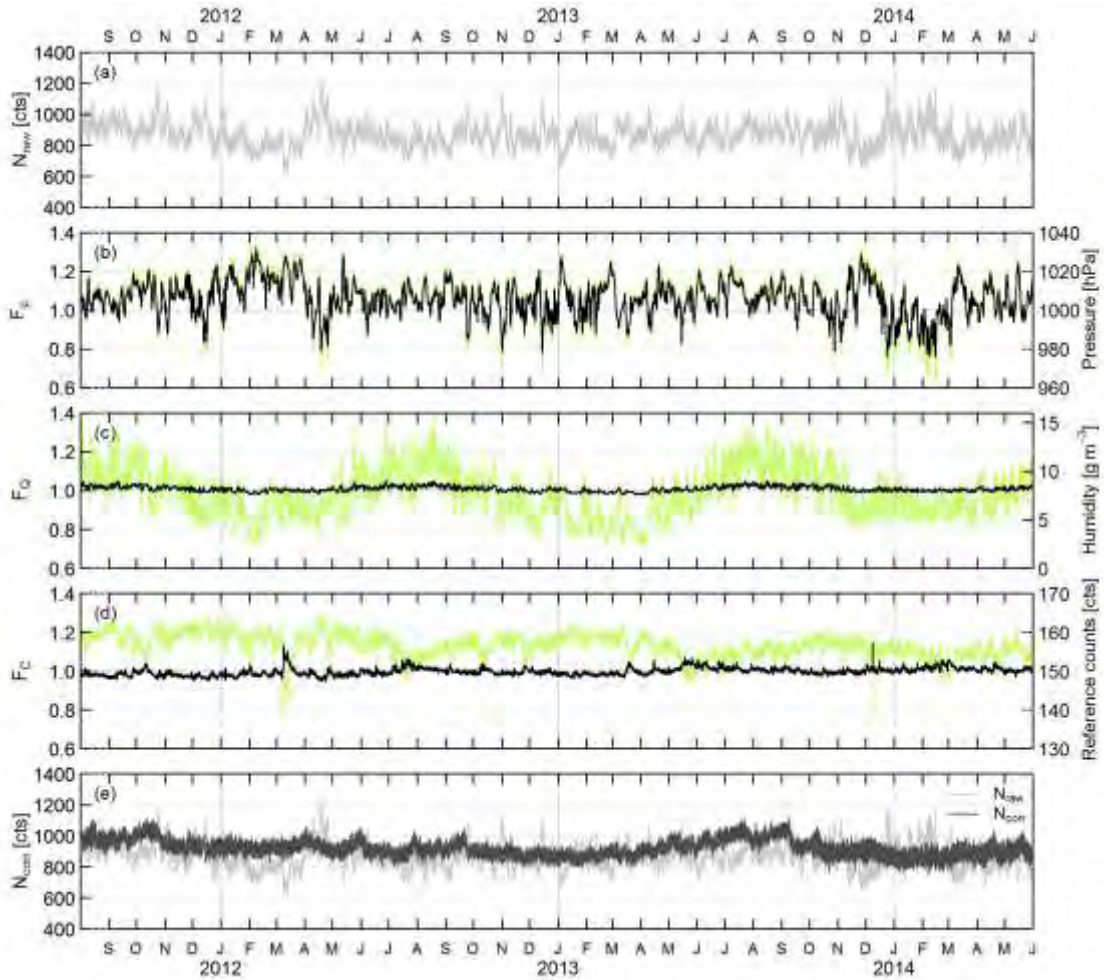
Corrections to Neutron Counts



Raw neutron counts (N_{raw}) and the correction factors applied (F_p, F_Q, F_C, black lines) to obtain corrected counts (N_{corr}) for CHIMN. Relevant variables (p, Q, C) are also shown in each case (green lines, right-hand axes). The temporal resolution of the data is 60 min.

Evans et.al. (2016) Hydrololgical Processess

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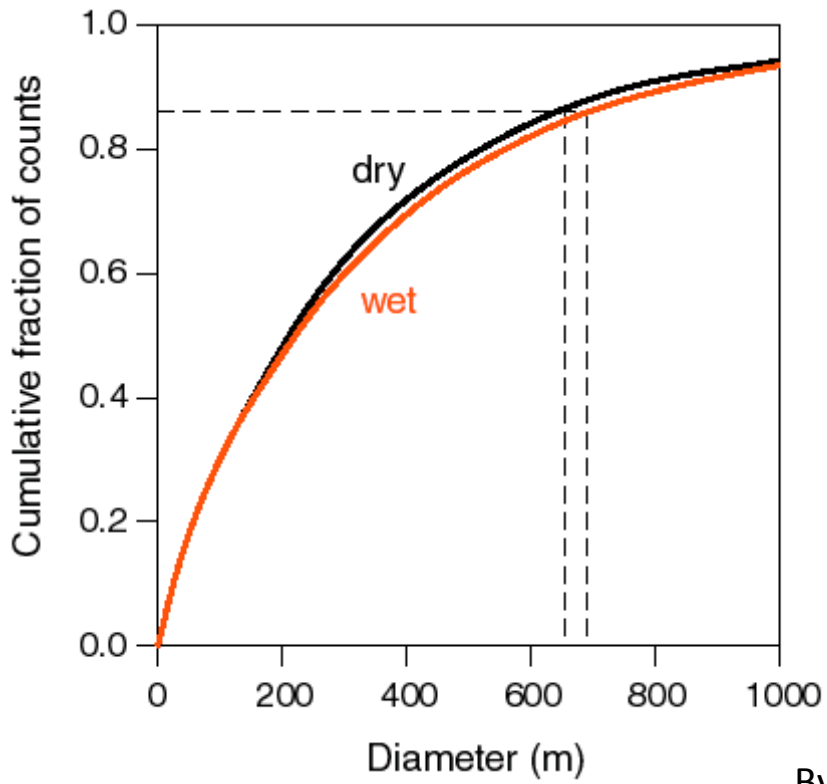
COSMOS Measurement area (modelled)

COSMOS integrates soil moisture over >200 m radius

- Footprint is mostly independent of soil moisture
- Footprint increases with altitude (decreasing pressure)



By Marek Zreda

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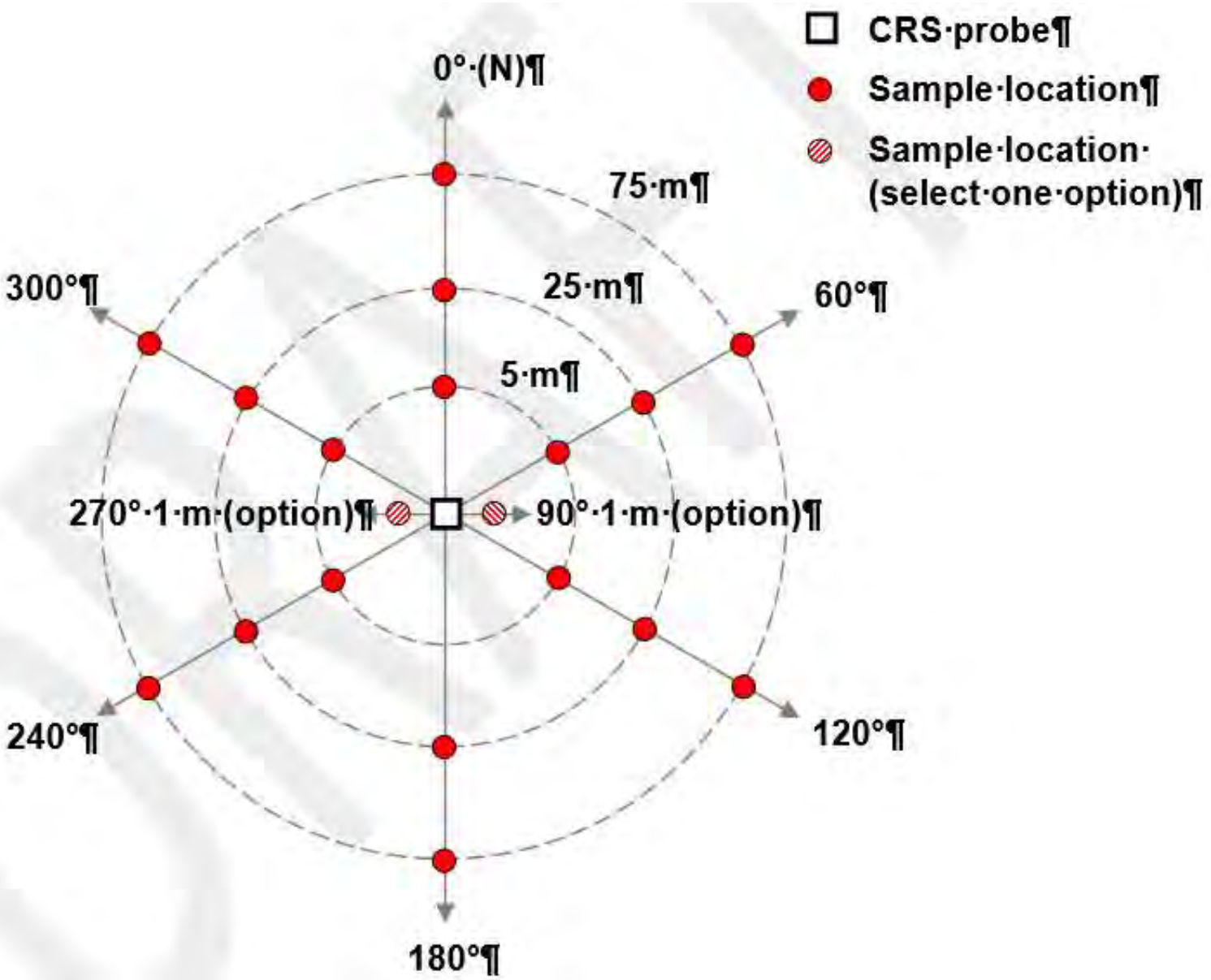
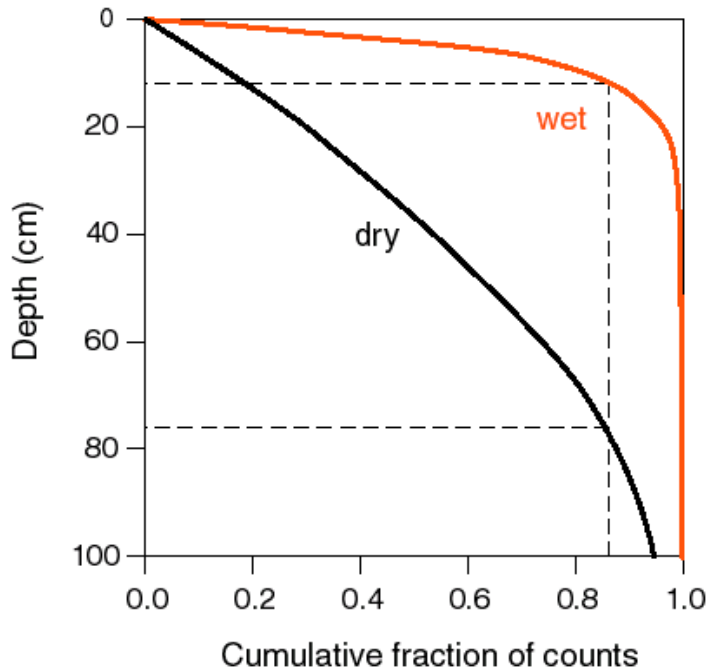
Calibration of Static COSMOS Sites



Measurement depth (modelled)

COSMOS integrates soil moisture from the surface to a depth of 12-70 cm *depending on the soil moisture content*

- 86% of neutrons from within 70 cm soil depth for very dry conditions
- In very wet soils only neutrons from the top 12 cm reach detector
- neutron source soil depths are independent of altitude (pressure)



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Current network

- UK wide coverage
- Varying spatial density
- Range of climate, land cover, soils, geology, topography
- ‘Simple’ grassland
- Build on existing research / networks
- Pragmatic approach

	Installed
Total	41

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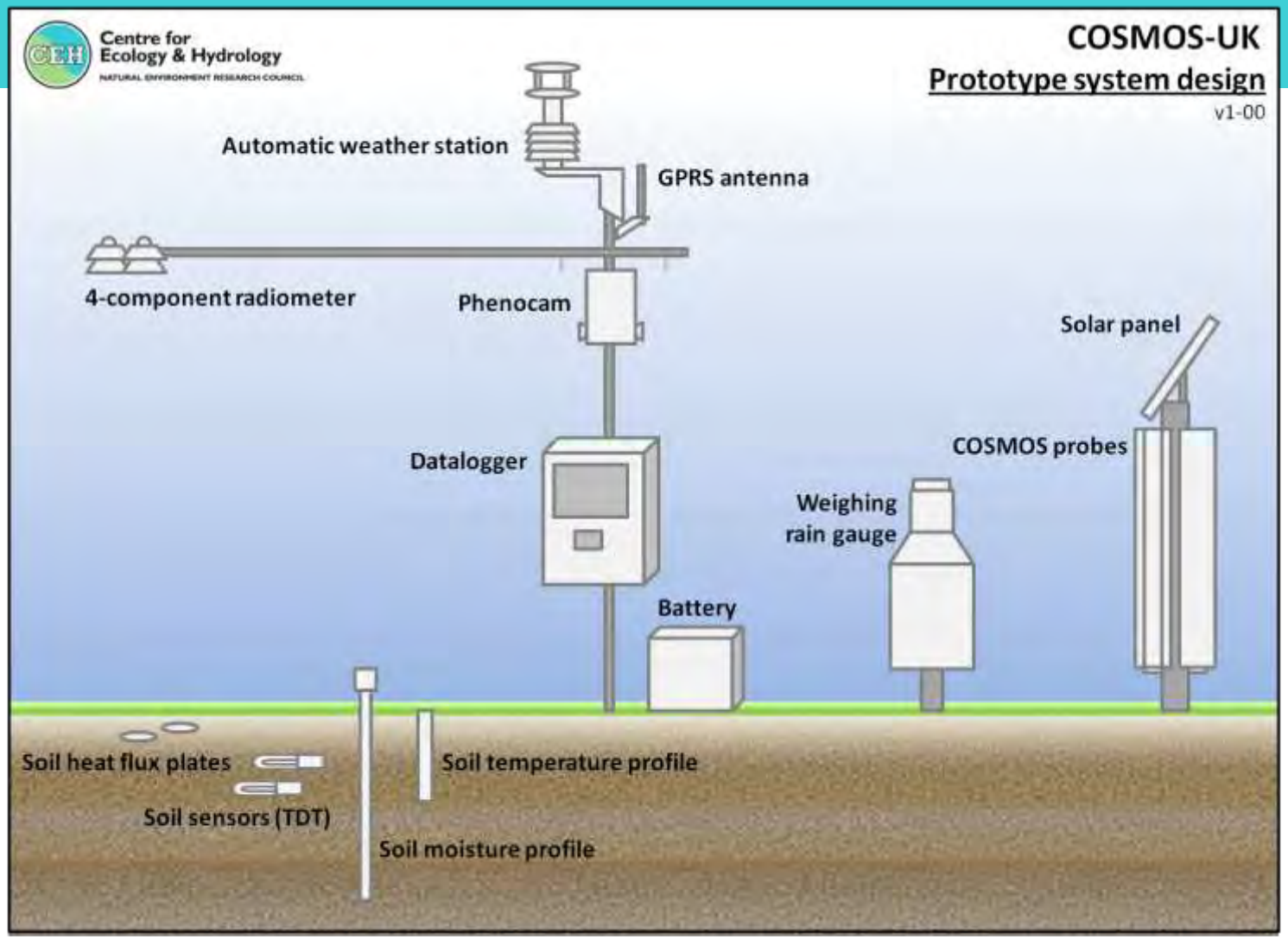
A typical COSMOS-UK monitoring site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COSMOS-UK
Prototype system design
v1-00
Automatic weather station
GPRS antenna
4-component radiometer
Phenocam
Solar panel
COSMOS probes
Datalogger
Weighing
rain gauge
Battery
Soil heat flux plates
Soil temperature profile
Soil sensors (TDT)
Soil moisture profile

IMKO PICO-Profile Soil Moisture

- Profile probe with three sensors at 15 cm, 40 cm and 65 cm.
- Installed in access tube and is sensitive over a radius of around 10 cm
- Not calibrated to the site specific soil type, but rely on generic calibration information.
- Air gaps around the installation tube can have a detrimental effect on instrument accuracy.
- Sensor faults due to water damage! No longer installed on new stations!

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TDT Point Soil Moisture Sensor

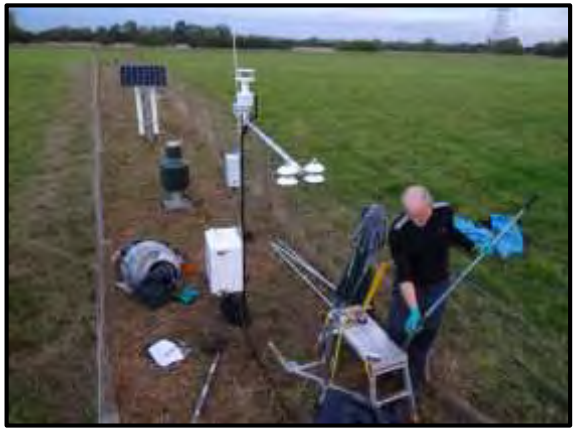
- Model: Acclima Digital SDI-12 TDT Soil Moisture Sensor, Acclima Inc., USA (with precision soil temperature)
- TDT = time domain transmissometry, using very high frequency around 2GHz
- New TDR-315 model for 2017, see http://www.acclima.com/poc7/products.html
- Blonquist, J.M., Jones, S.B., Robinson, D.A., 2005. A time domain transmission sensor with TDR performance characteristics. Journal of Hydrology 314, 235-245.

Phase 1 Installation Works

OTT Pluvio II install at SHEEP

Acclima TDT & Soil heat flux plate

Gill Metpak



IMKO installation, CHIMN

Chimney Meadows , Bampton, Oxfordshire (CHIMN)

Hukseflux STP01 soil temperature profile

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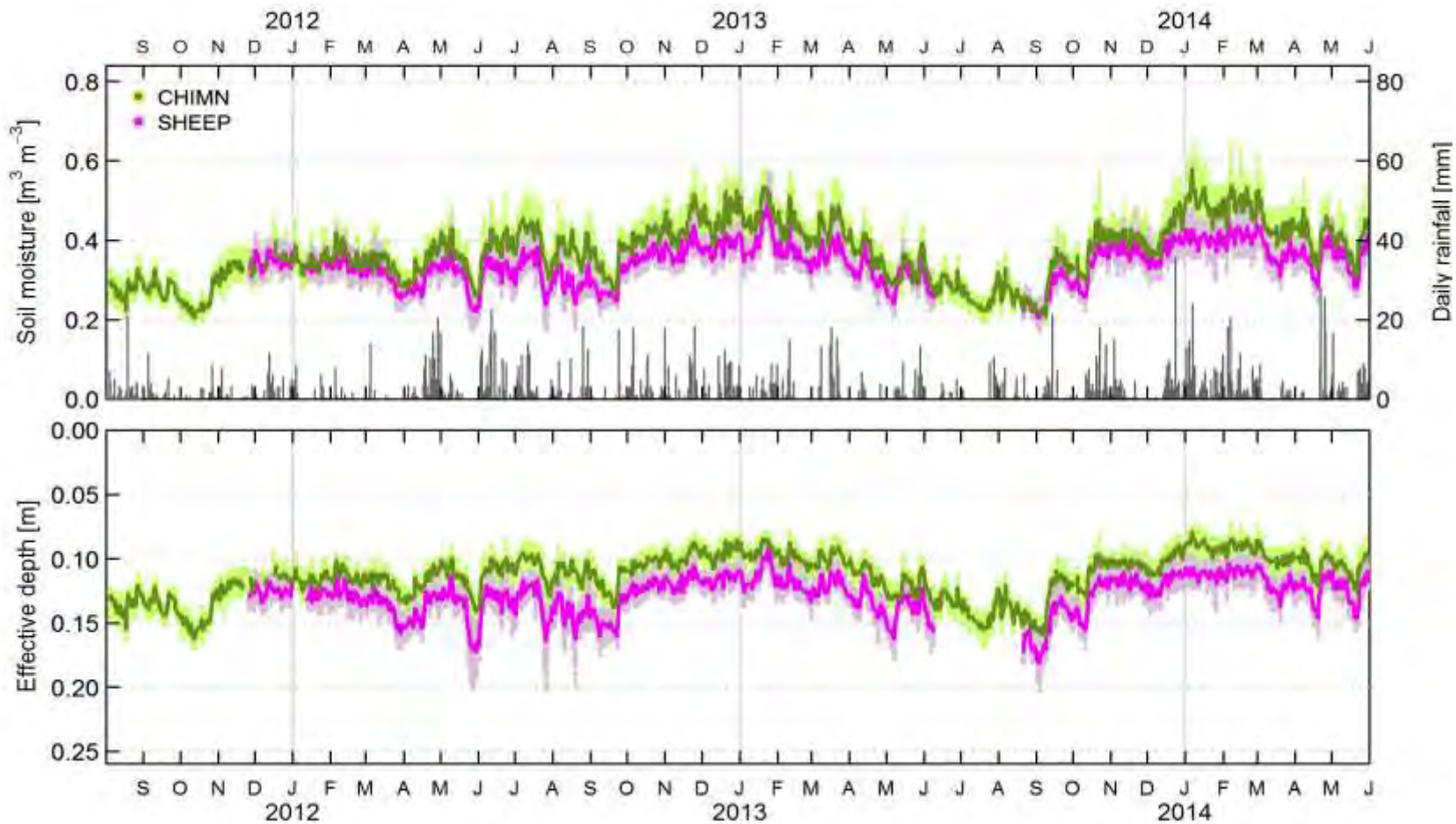
COSMOS Data



Daily averages (lines) and 6-h running means (shading) of COSMOS soil moisture content and modelled effective measurement depth

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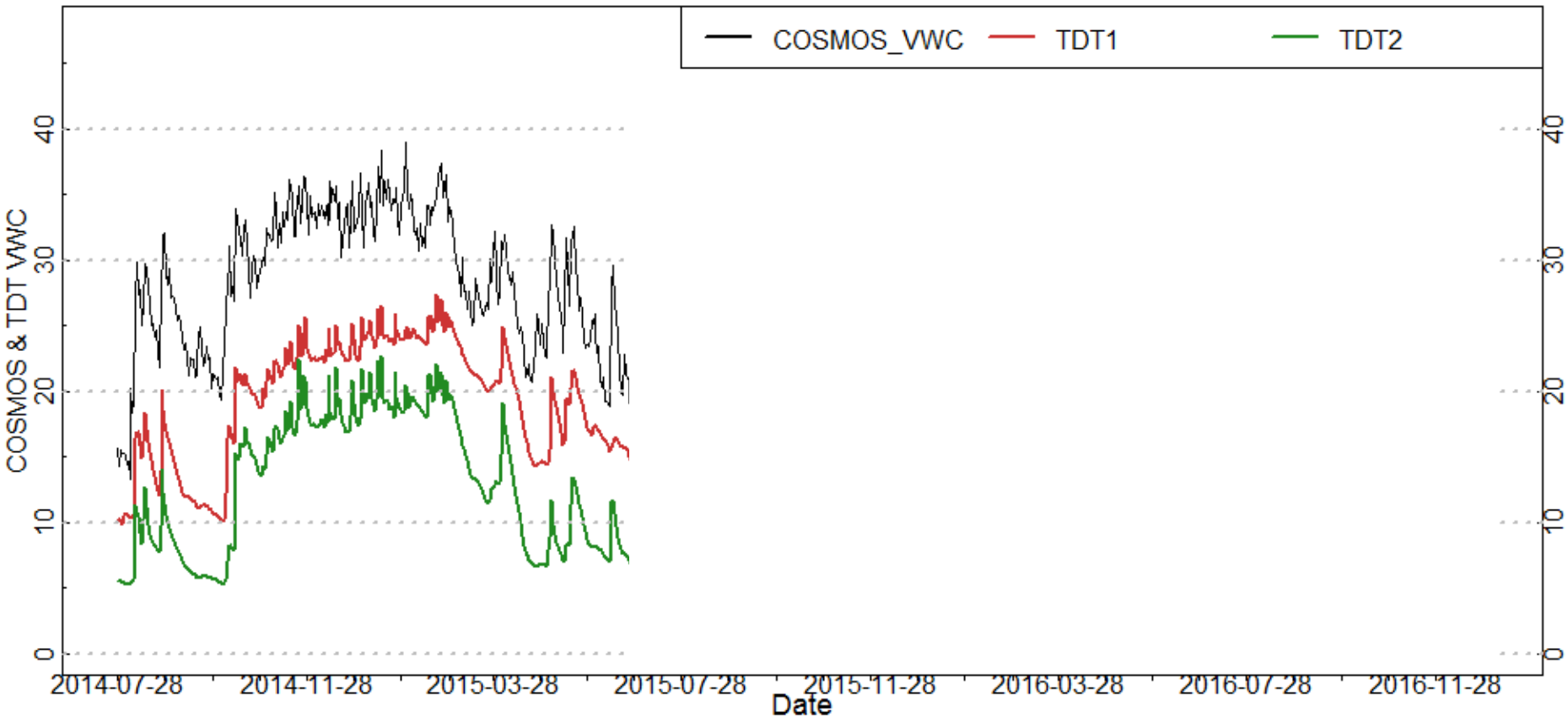
Other soil moisture sensors (1)



Daily data from Rothamsted

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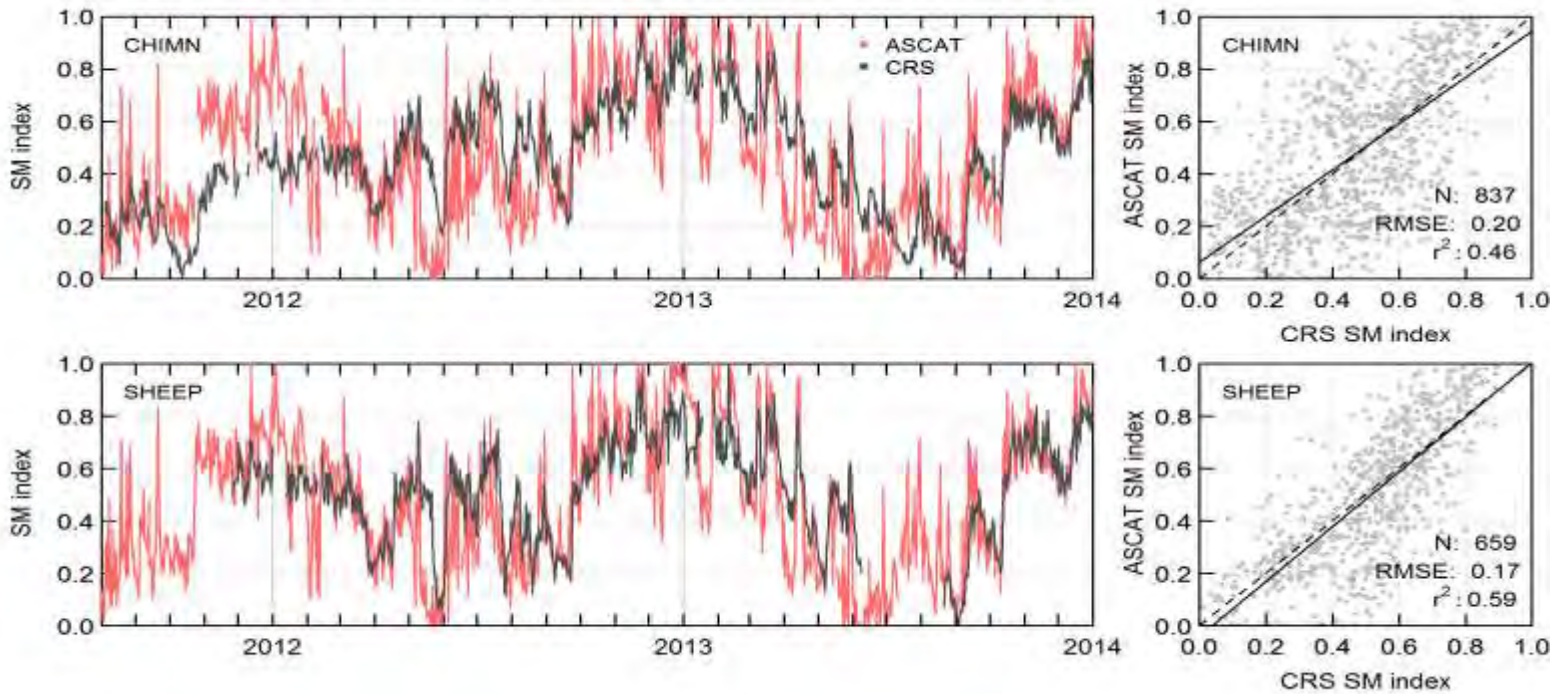
COSMOS & ASCAT SM Indices



Soil moisture indices from COSMOS and ASCAT data for Chimney Meadows and Sheepdrove Organic Farm (August 2011-December 2013).
The resolution of the data is daily. Dashed lines are 1:1; solid lines are linear regressions through the data.

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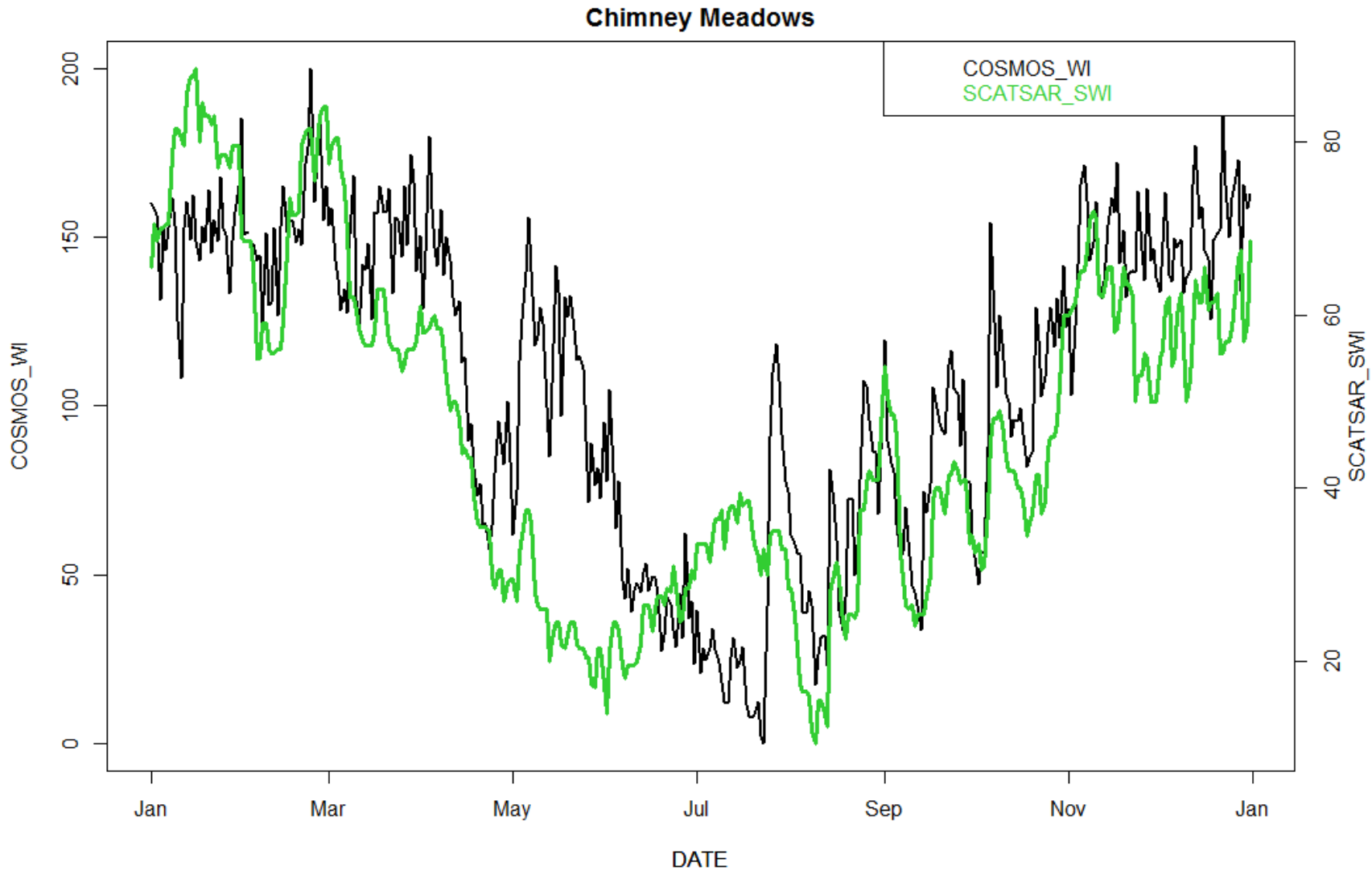
SCATSAR_SWI Derived Using Both Sentinel-1 and ASCAT



2015

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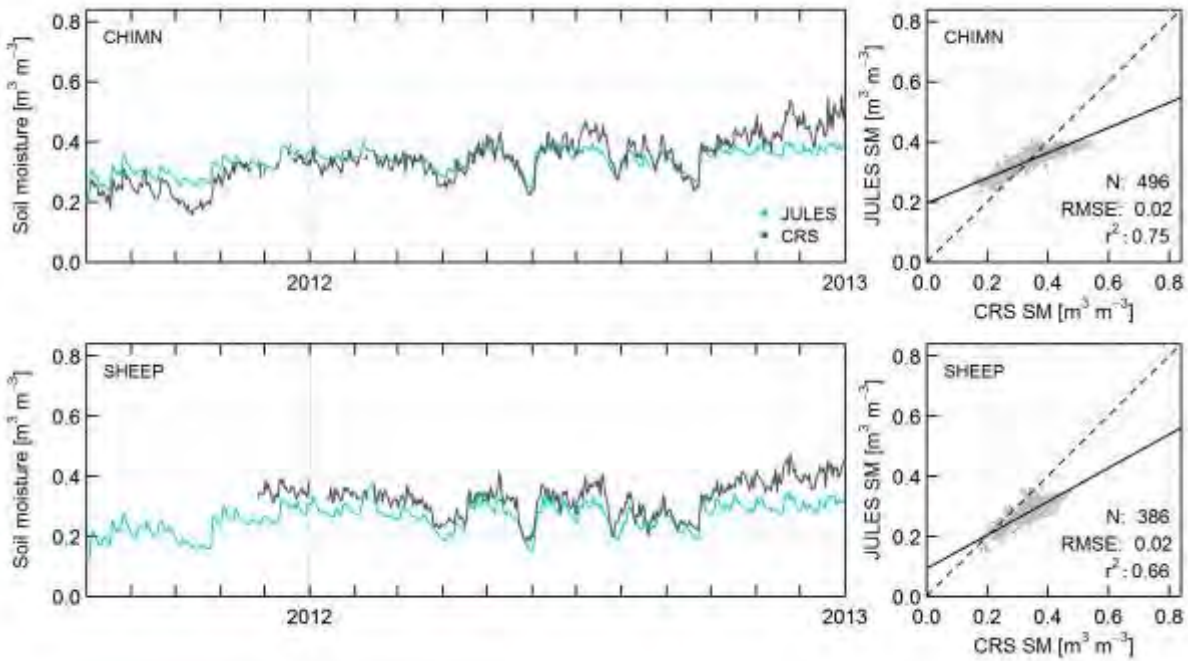
CRS SM compared with JULES



VWC from CRS probes compared to 10 cm SM from the JULES model for Chimney Meadows and Sheepdrove Organic Farm

J. G. Evans et. al., 2016. "Soil water content in southern England derived from a cosmic-ray soil moisture observing system – COSMOS-UK" Hydrological Processes
http://onlinelibrary.wiley.com/doi/10.1002/hyp.10929/full

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Questions ?

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Sensors

- Goal is to measure water and energy balances
- research grade weather station, 4-component radiometer, heat flux plates and soil temperature profile
- Point soil moisture sensors (x2) at 10 cm, and soil moisture profile – for ‘sense’ check.
- High accuracy, low maintenance weighing rain gauge.
- All sensors logged on a Campbell CR3000 with GPRS telemetry.

Weighing Rain gauge: The OTT Pluvio²

- Measures quantity and intensity of solid and liquid precipitation.
- On-board processing algorithms account for spurious changes due to temperature, wind speed, and evaporation from the collecting bucket
- Requires manual emptying of bucket once or twice per year.
- Low maintenance, self-diagnostics

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Completed Phase 1 Sites

Sheepdrove Organic Farm, Lambourn, West Berkshire (SHEEP)

Waddesdon Manor Farm, Buckinghamshire (WADDN)
Note: only moderated CRS-1000 tube installed

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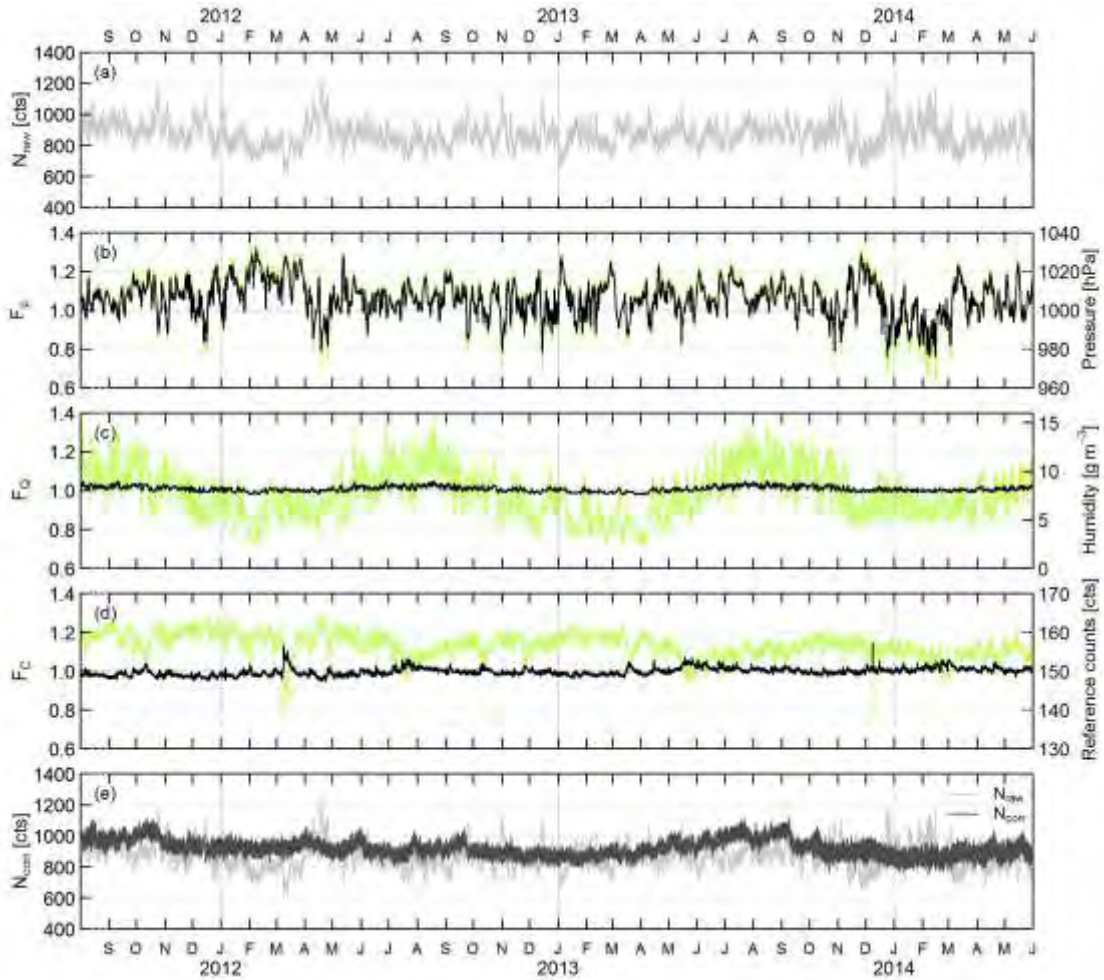
Corrections to Neutron Counts



Raw neutron counts (N_{raw}) and the correction factors applied (F_p, F_Q, F_C, black lines) to obtain corrected counts (N_{corr}) for CHIMN. Relevant variables (p, Q, C) are also shown in each case (green lines, right-hand axes). The temporal resolution of the data is 60 min.

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Data Flows

- Automated telemetry of data in real-time
- Automated calibration & quality control
- Data continuously archived to CEH Oracle database
- Data requests currently served manually




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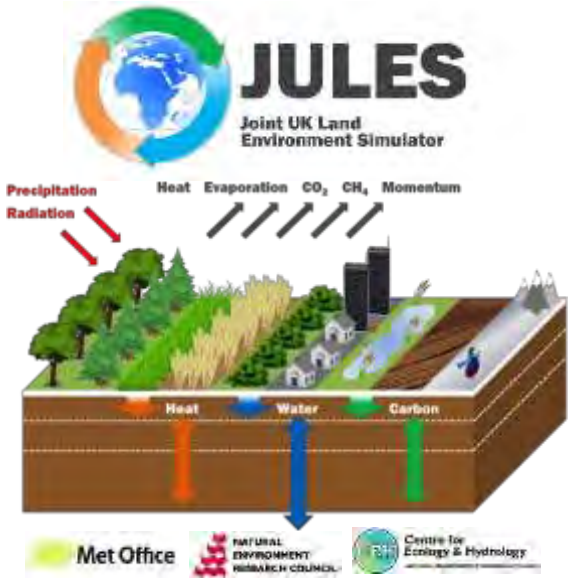
Data Assimilation: COSMIC

- The variable measurement depth of the Cosmic-ray Soil Moisture Sensor compared to the constant soil moisture depth layers in land surface models (LSM) *could* be a disadvantage.
- But by using the predicted soil moisture from the LSM to predict the expected neutron count circumvents this issue.
- The COsmic-ray Soil Moisture Interaction Code (COSMIC[1]) provides an analytical model to predict neutron counts from the LSM, allowing data assimilation of measured counts.



1.Shuttleworth et.al. 2013, HESS

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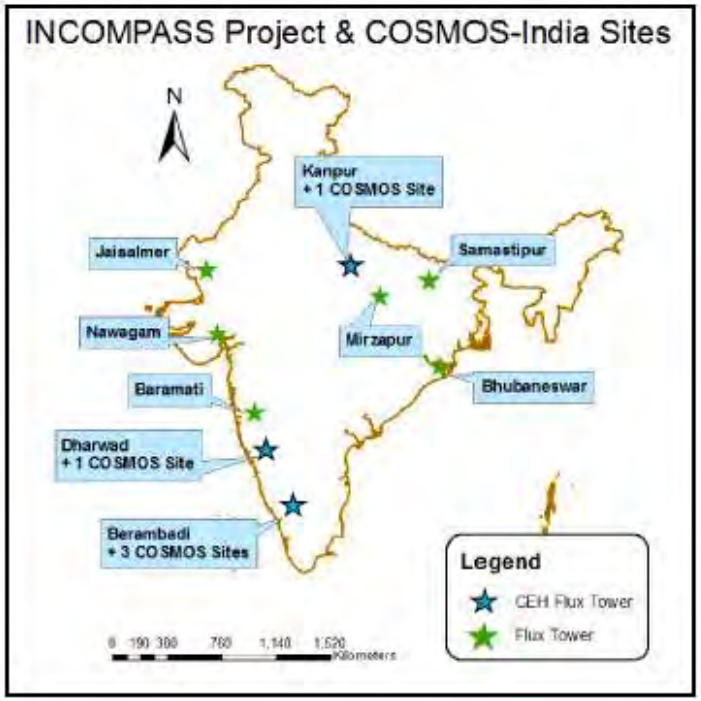
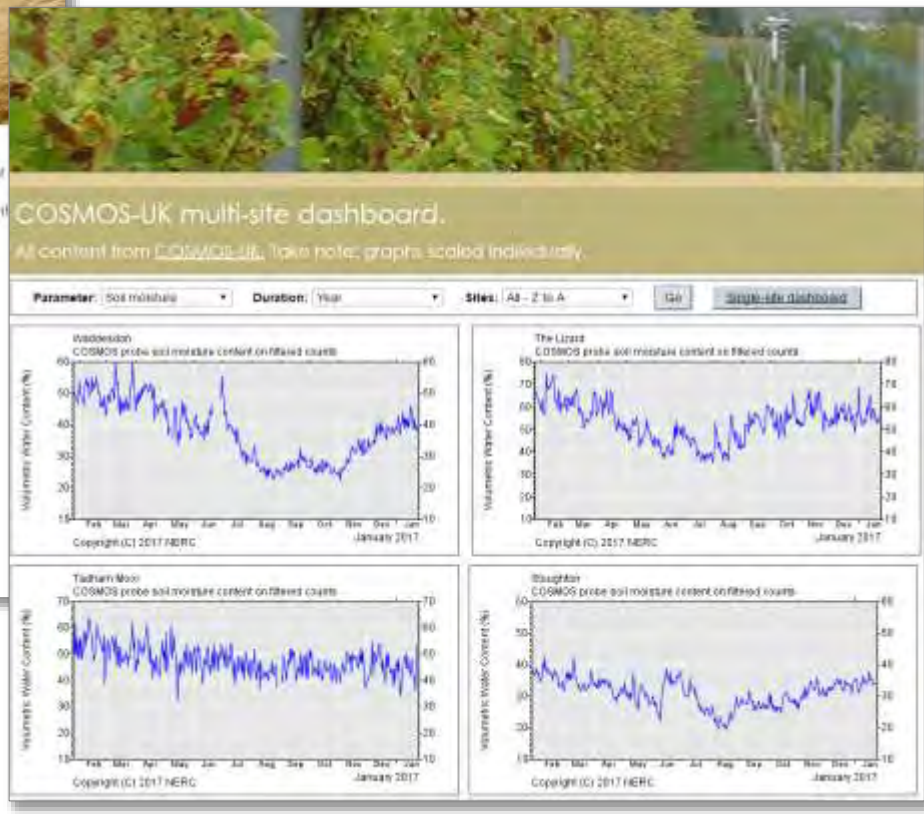
Land Surface Flux Measurements Projects Sites

0 40 80 160 240 320 Kilometers

Legend
- COSMOS-UK Site
- Discontinued
- Brattleby Project



Web resources



http://cosmos.ceh.ac.uk/

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