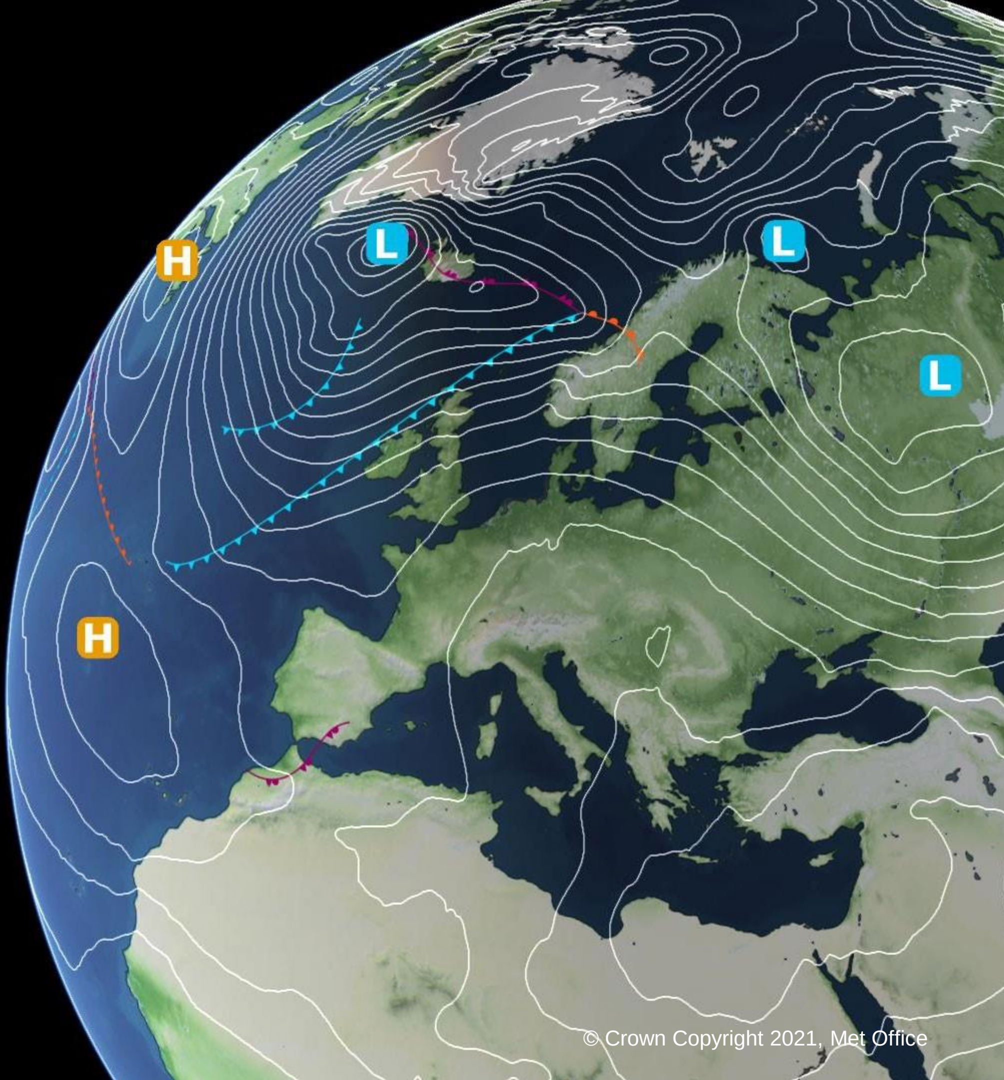
Met Office

Snow-free land observations

Cristina Charlton-Perez

ECMWF Annual Seminar: Observations

September 2021



Acknowledgements

- Brett Candy, Breo Gomez, Samantha Pullen, Jo Waller and Chris Harris (Met Office)
- Mel Sandells (U. Northumbria)
- Stephane Belair, Marco Carrera and Bernard Bilodeau (Environment and Climate Change Canada, ECCC)
- Patricia de Rosnay and Stephen English (ECMWF)
- Clement Albergel (ESA)
- Imtiaz Dharssi (Bureau of Meteorology)
- Sujay Kumar (NASA GSFC)
- Liz Cooper and Rich Elis (CEH)
- Tristan Quaife and Ewan Pinnington (U. Reading)
- Zaid Sassi (CESBIO)
- Isabel Franco Trigo (IPMA)
- Ian Davenport (Edinburgh University)

Annual Seminar (2014) previous talk on Observations of land (Brett Candy) had a focus on Satellite observations.

c.charlton-perez@metoffice.gov.uk

Three takeaway messages…

1. **Land observations are important**
   - To weather (NWP), hydrological and climate forecasting.
   - For improving land surface models.
   - To applications influencing human life: agriculture, flooding, drought, heatwaves and wildfires.
2. **Requirements depend on the application**
   - Observations not currently meeting operational timeliness required for NWP can still be useful for climate.
   - Gaps exist but current observing systems can complement each other.
3. **Future of land observations**
   - Higher resolution spatial and temporal obs. for convection-permitting NWP models and frequent DA cycling.
   - Follow-on satellite missions for the passive (L-band: SMOS, SMAP) and active (ASCAT) sensors should ensure the data is reliable and timely.
   - Financial and technical support for existing and new ground-based networks around the world.
   - Investment in scientists and technicians to use the observations we have.

c.charlton-perez@metoffice.gov.uk

Why are land observations important?

Met Office

Why is land/soil important? At the intersection of …

Geosphere

Rocks and minerals on Earth, sand, dirt and all the abiotic (non-living) parts of soils determine the albedo of the surface and structure of the soil (texture, density and porosity).

Literally where we stand, cultivate and build.

Atmosphere

Energy (LH and SH) exchanges with soil influence (evaporation) the near surface temperature and humidity implications for heat waves and drought.

[Soils can be a source and sink for greenhouse gases]

Weather and climate forecasts

Biosphere

Plant growth is regulated by soil moisture availability (transpiration). [Soil biota] are micro-organisms (bacteria, fungi, archaea and algae) & soil animals (protozoa, nematodes, mites, springtails, spiders, insects, and earthworms).

[Soils are 'bioreactors'] consumption and production of different gas species

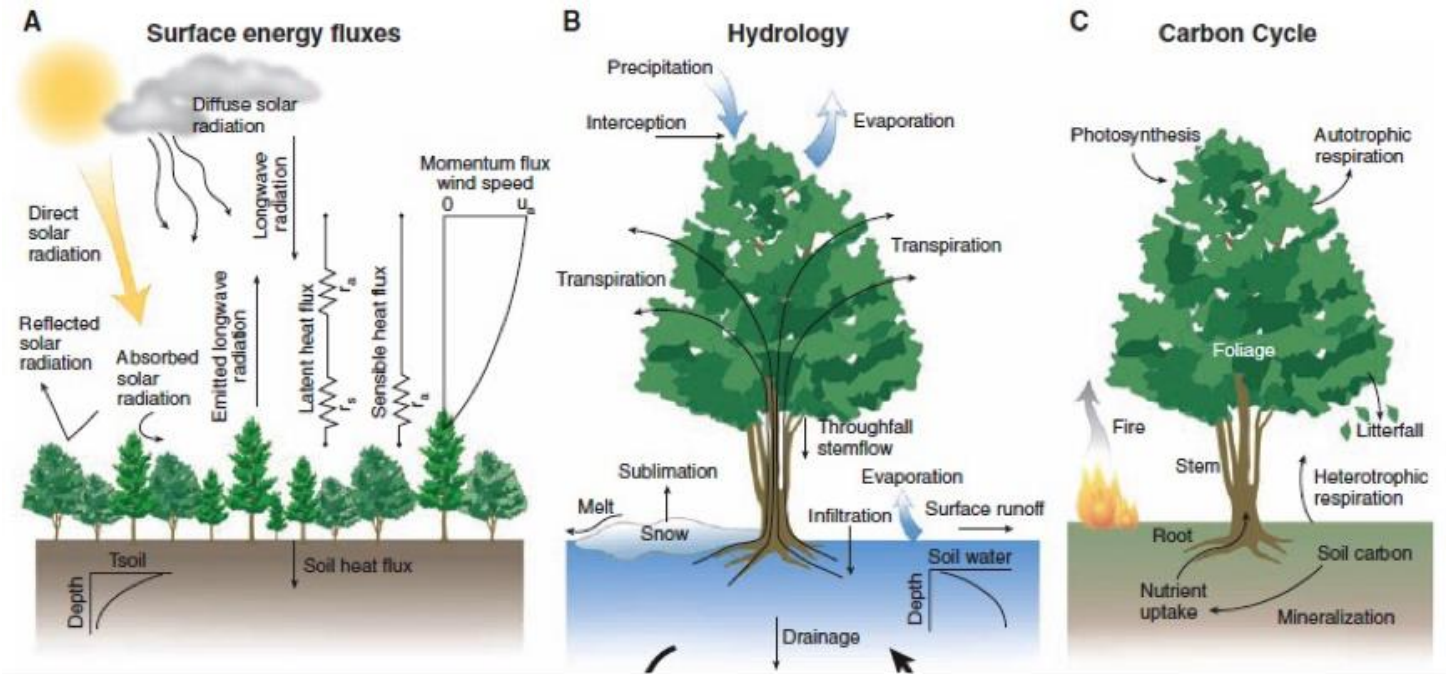
Agriculture, wildfire fuel

Hydrosphere

Soil determines how the precipitation is partitioned into surface runoff, infiltration, and sub-surface flow influencing groundwater recharge and flooding.

Water resource management

Met Office



[Reference: Bonan, G.B. Science, 320,1444-1449 (2008)]

Non-snow land variables

- Albedo 1
- **Soil moisture (SM)**
- Land surface temperature (LST) 1, 2
- Leaf area index (LAI) 1, 2, 3
- Vegetation Optical Depth (VOD) 1, 2

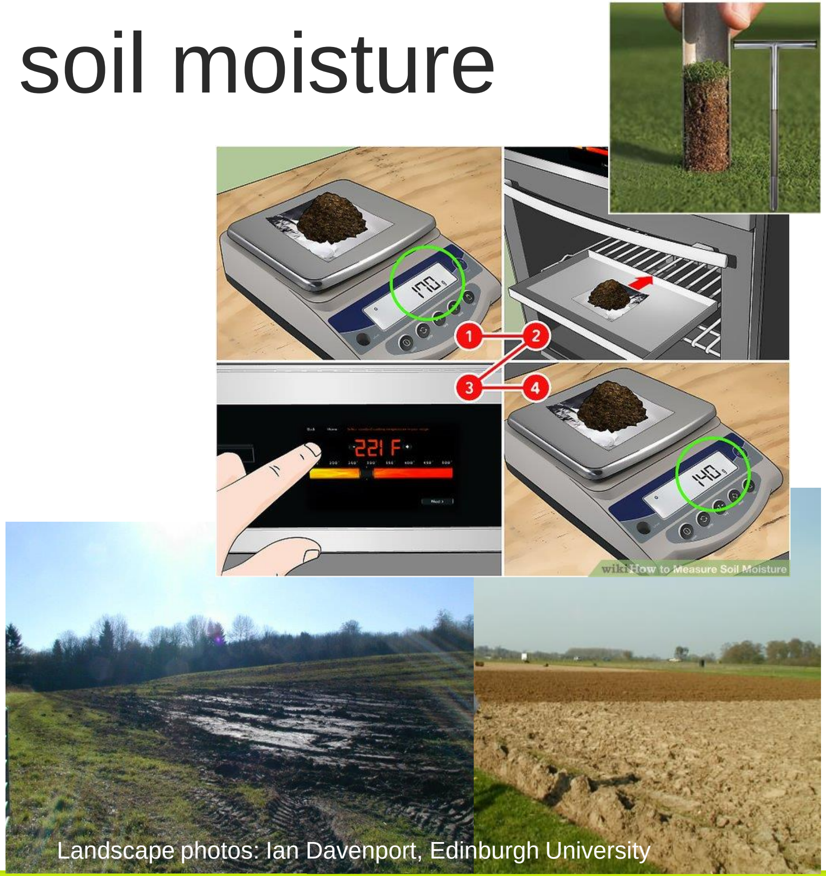
Essential climate variables (ECV)

Presence of snow cover changes soil behaviour Snow observations, M. Sandells, Monday 16:25

c.charlton-perez@metoffice.gov.uk

Met Office

Observations hierarchy for soil moisture



Landscape photos: Ian Davenport, Edinburgh University

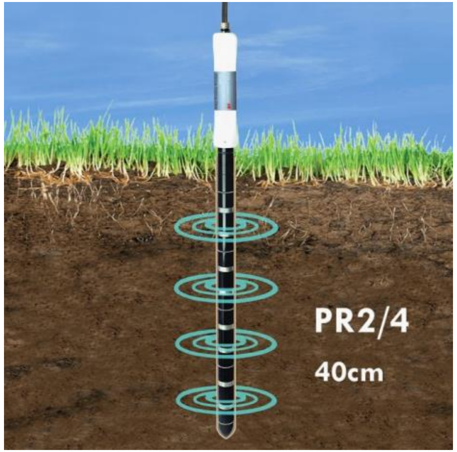
Soil has high spatial variability

1. Gravimetric method as ground truth vs. sensors
2. Traditional point Sensors
3. Active neutron sensors (not widely used)
4. Passive COSMOS cosmic ray sensors (becoming more common)
5. Satellite-based active and passive frequent global coverage

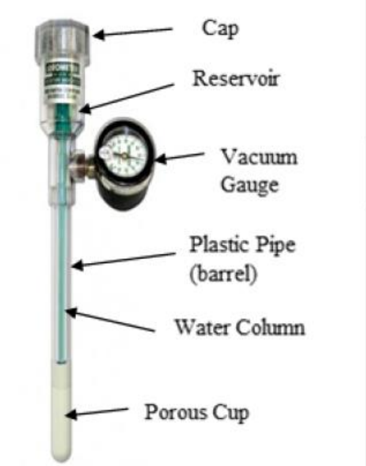
c.charlton-perez@metoffice.gov.uk

In situ instruments to measure soil moisture

Time delay reflectometry (TDR)



Capacitance soil moisture sensor probe. Photo: Delta-T Devices



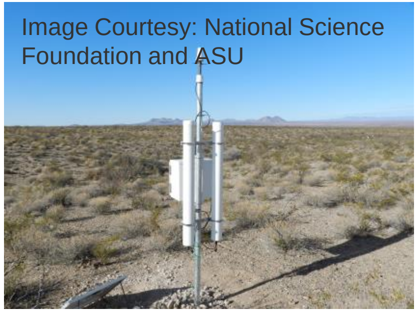
Tensiometer

- International Soil Moisture Network (ISMN) website and Recent retrospective (2021)
- ISMN better coverage over N. America, Europe and Asia and sparse over Africa, Australia and South America
- China Meteorological Service Centre collects data from a ground-based network
- Probes sense (up to 2 m) greater than depth satellites (first few cm)

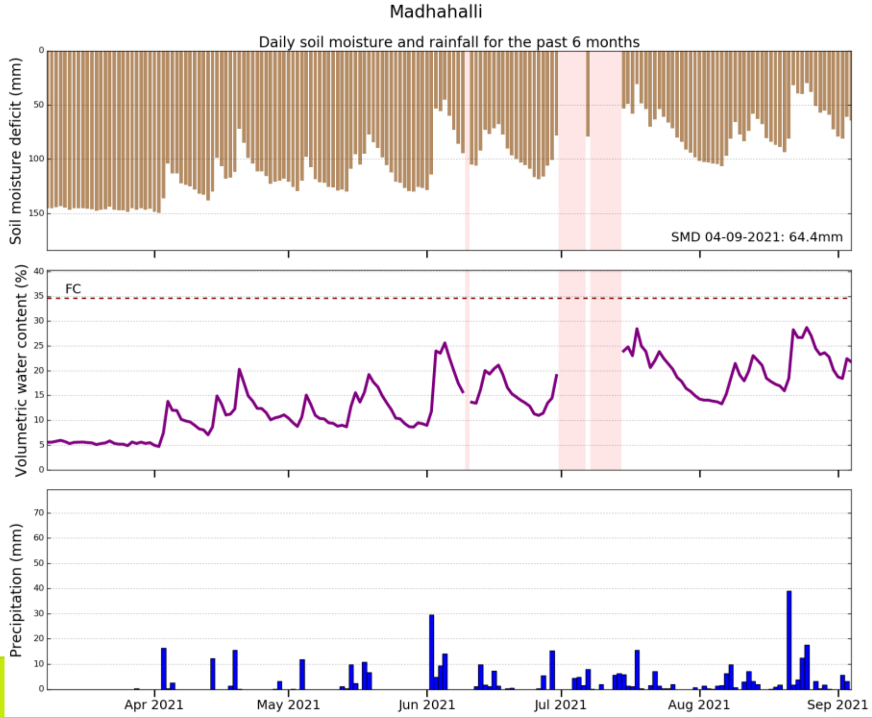
Images Courtesy V. Sharma, U. Minnesota

Met Office

In situ soil moisture via neutron count

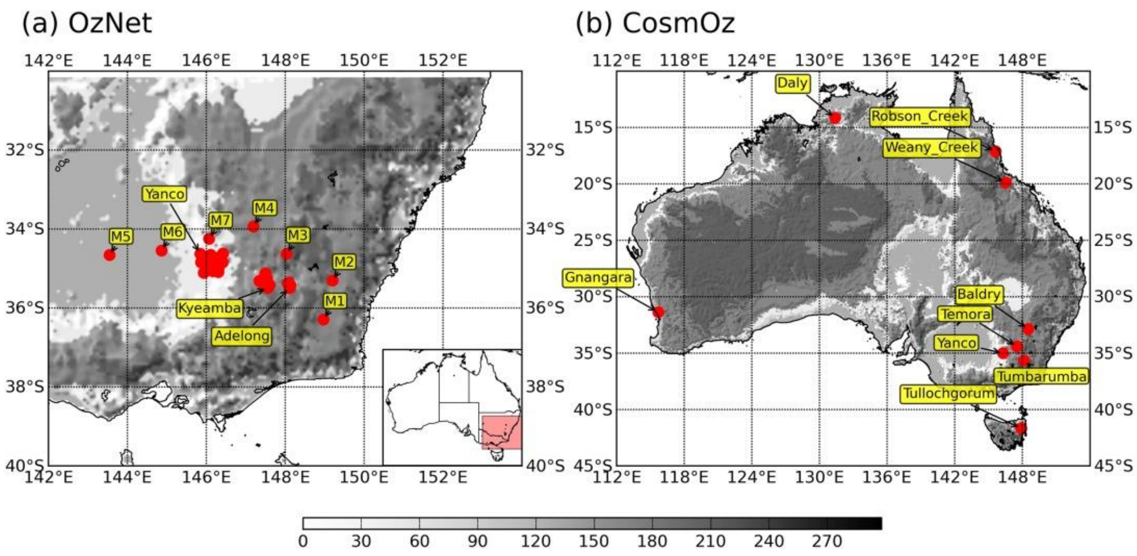


- Detect particles interacting with hydrogen atoms in water
- Inverse correlation between above ground measured neutron intensity and environmental water content
- **Active**: neutron probes radiation source (active). No longer used in the UK
- **Passive** COSMOS instrument (pictured) networks in Australia, UK, USA, India
- Horizontal footprint (~10-200 m) larger than in situ probes and smaller than satellites



Met Office

Soil moisture Surface Networks



Surface elevation (m) at 10km resolution.

Australian soil moisture observing networks: (a) OzNet and (b) CosmOz Image courtesy [Vinodkumar, et. al. (2017)]

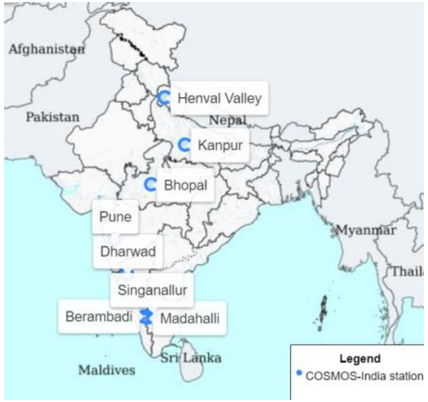


Image courtesy: [COSMOS India]

Image courtesy: [COSMOS-UK] and UK Centre for Ecology and Hydrology

Met Office

Soil Moisture via satellite

- Measurements from satellite instruments can be translated to a soil moisture quantity
- Water has dielectric properties that can be measured in the microwave channel
- Passive (L-band) radiometer instruments (e.g. SMOS, SMAP) soil moisture retrieved using Bayesian or neural net approach
- Active (C-band) scatterometer instrument (ASCAT on MetOp-A, -B and –C) Soil wetness index determined via backscatter change detection algorithm
- Depth of measurement generally shallow
- Can depend on soil moisture itself (e.g. arid land) and thickness of vegetation (e.g. ASCAT)

MetOp platform
Image Courtesy ESA

SMOS 50 km footprint
Image Courtesy: Ian Davenport, Edinburgh University

c.charlton-perez@metoffice.gov.uk

Past and present satellite sensors

OSCAR Observing Systems Capability Analysis and Review Tool

Passive microwave sensors

- Scanning Multichannel Microwave Radiometer (SMMR) Nimbus-7, Special Sensor Microwave - Imager (SSM/I) ,Microwave imager of Tropical Rainfall Measuring Mission (TMI), Advanced Microwave Scanning Radiometer –Earth Observing System (AMSR- E) Aqua and AMSR-2, Advanced Microwave Scanning Radiometer 2 (AMSR2) WindSAT, MWRI
- Soil Moisture Ocean Salinity (SMOS) MIRAS instrument
- Soil Moisture Active Passive (SMAP) mission. Radar failed early on and passive remains functional

Active sensors Scatterometers

- European Remote Sensing (ERS-1/2) satellites
- Advanced Scatterometer (ASCAT) of the Meteorological Operational satellite program (MetOp-A/B/C) (starting 2007)

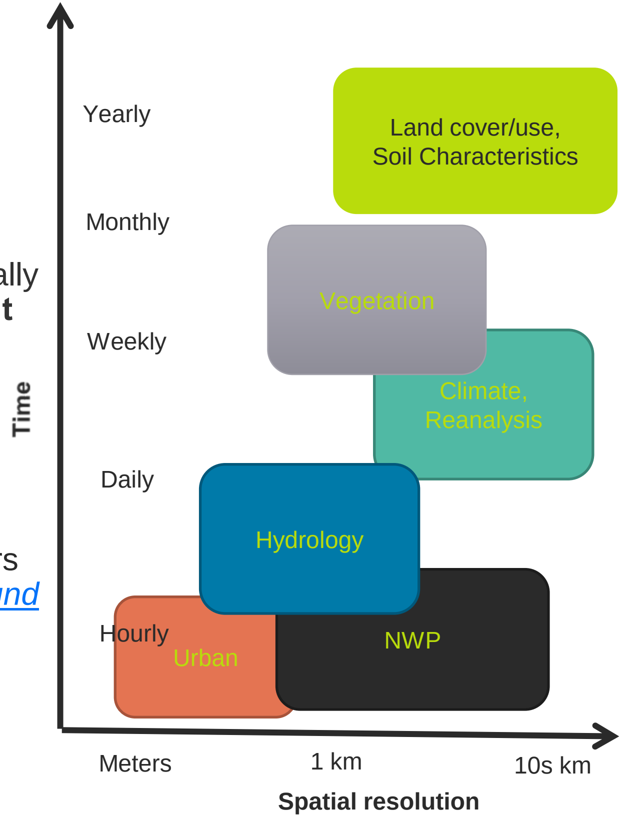
c.charlton-perez@metoffice.gov.uk

Applications: Where are the gaps?

Met Office

Applications

- [Reanalysis products]“are a blend (DA) of observations with past short-range weather forecasts rerun with modern weather forecasting models. They are globally complete and consistent in time and are sometimes referred to as **‘maps without gaps’**.” ECMWF
- Weather forecast initial conditions (e.g., Met Office operational soil analysis system)
- Land surface model (LSM) improvements. Field campaigns are important for estimating model parameters, but large areas of quality long-term observations provide sound empirical grounding for determining land surface model parameters such as *dry-down timings*, *pedotransfer function coeffcicients 1* *and* *2*, *bare ground evaporation*, *and* *soil texture*.
- Hydrological forecasts and wildfire forecasts e.g. fuel forecasts (BoM, Australia)
- Climate: improve modelling, ancillaries, context for climate change scenarios
- Hierarchy of observations enables validation and calibration of new soil observations and reanalysis products (via for e.g., triple collocation method Stoffelen (1998))



c.charlton-perez@metoffice.gov.uk

Land Reanalysis

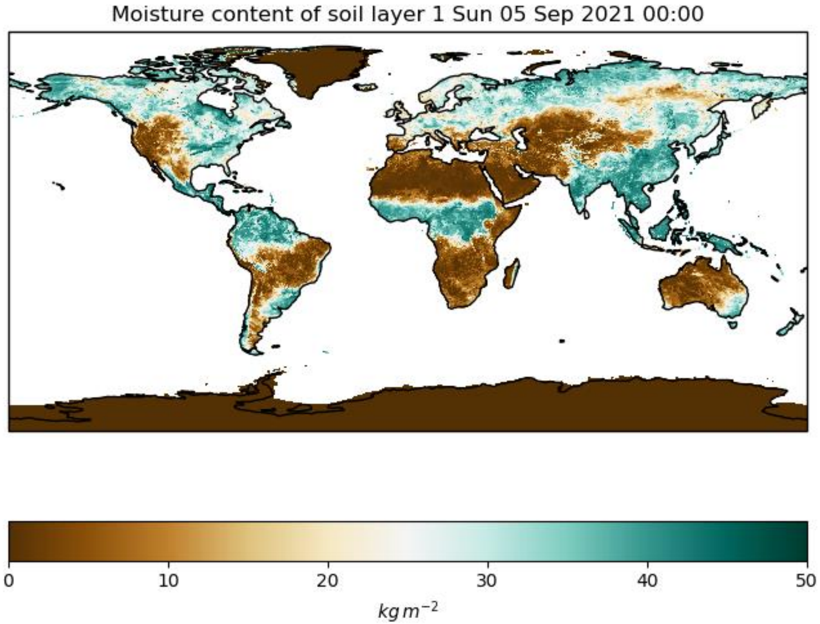
- Reconstructed long term global data sets “Maps without gaps”
- Land surface models (LSM) (e.g., H-TESSEL, Noah, JULES, ORCHIDEE) provide link between energy and moisture fluxes at the land-atmosphere interface
- Land observations used indirectly via climatologies and land/soil maps
- Soil moisture observations are assimilated as part of production in some

1. Japanese Reanalysis JRA-55
2. NCEP-NCAP reanalysis and subsequent CFSR
3. NASA MERRA and subsequent MERRA-2 not directly assimilating land variables recommendation to include in follow-on to MERRA-2.
4. ERA-Iterim and subsequent ERA-5 (ERA-5 includes scatterometer data from AMI on ERS-1 and ERS-2 (1991-2006) and ASCAT on MetOp-A, -B (2007-2014)
5. ESA CCI data sets include (v06.1 product) 4 active and 10 passive microwave sensors

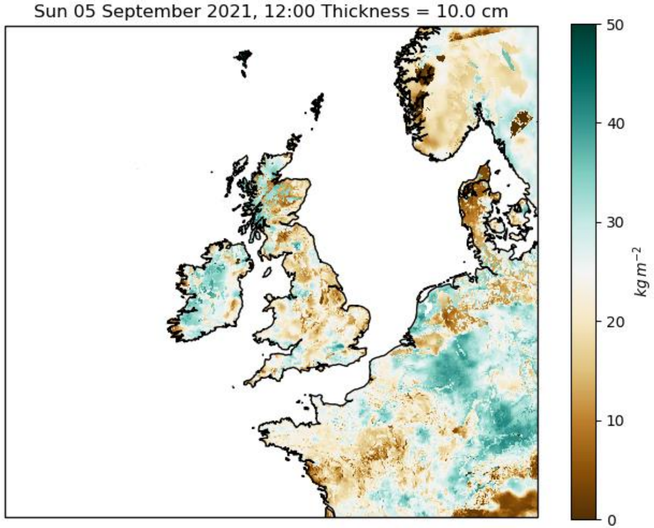
c.charlton-perez@metoffice.gov.uk

Example: Met Office Operational Soil Moisture Analysis System

Global analysis



Regional model analysis



ASCAT soil wetness is the soil moisture product assimilated operationally

c.charlton-perez@metoffice.gov.uk

Operational Prediction

Soil moisture observations are used in data assimilation to produce initial conditions, the "analysis" and must

- **arrive in time for production of forecasts.**
- **be reliable and continuous.**
- **be well-calibrated and errors should be understood.**

ECMWF

- ASCAT soil wetness,
- SMOS soil moisture = f(SMOS Tb, Neural Network),
- Pseudo-observations of T and q produced via 2D-Optimal interpolation scheme

Met Office Operational

- ASCAT soil wetness,
- Pseudo-observations of T and q produced via variational scheme

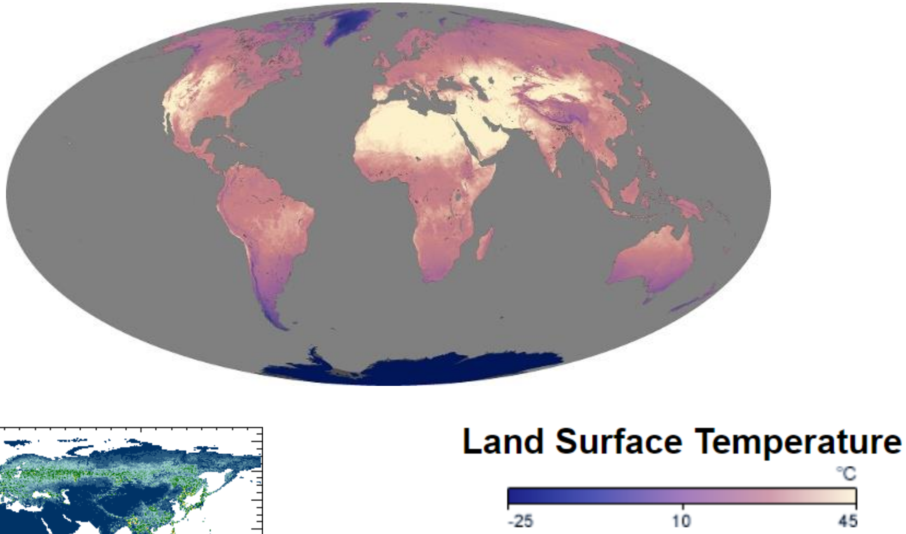
Environment and Climate Change Canada (ECCC)

- NWP: Pseudo-observations of T and q via EnKF
- Hydrology IC: assimilate SMAP+SMOS for soil moisture; GOES for land surface temperature, ensemble OI for terrestrial snow, for the High-Resolution (2.5 km, national) Deterministic Land Surface Prediction System (HRDLPS) which is input to hydrological prediction models

c.charlton-perez@metoffice.gov.uk

Climate requirements (ESA CCI ECV)

Timeliness not as critical for climate as in NWP

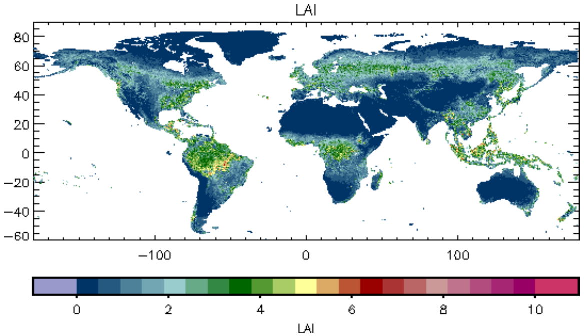


July 2021 Land Surface Temperature using data collected during the daytime by the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra satellite.
Image Courtesy: NASA

Global Surface Soil Moisture
- Daily
- 1-25 km resolution
- Uncertainty: 0.04 m3/m3
- Stability: 0.01 m3/m3 per decade

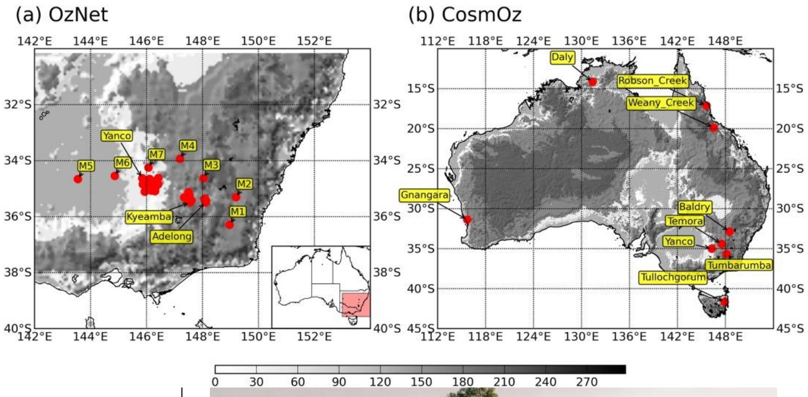
Global Land Surface Temperature Maps
- Every 3 hours
- 1 km resolution
- Measurement Uncertainty: 1K
- Stability: <0.1K per decade

Global Leaf Area Index (LAI)
- Daily
- 250m
- Uncertainty: max 15%



Met Office sample from monthly climatology.

c.charlton-perez@metoffice.gov.uk



Gaps

1. Land use is constantly changing. More frequent updates and evaluation of land cover maps and soil types.
2. Difficult to get reliable observations where the soil has large organic composition or non-grass vegetation. In situ network sites are often chosen for non-scientific, practical reasons.
3. Density of in situ (ground-based) networks can be improved and we must continue to maintain and calibrate current networks
4. Improved complexity and computational efficiency of LSM and data assimilation systems (e.g. forward operators).
5. Spatial (~1 km) and temporal (sub-daily) resolution for satellite products that are timely.
6. Follow-on missions for L-band passive radiometers.
7. Investment in time and people power to make better use of the observations we have.

c.charlton-perez@metoffice.gov.uk

Future of land observations?

Met Office

Future

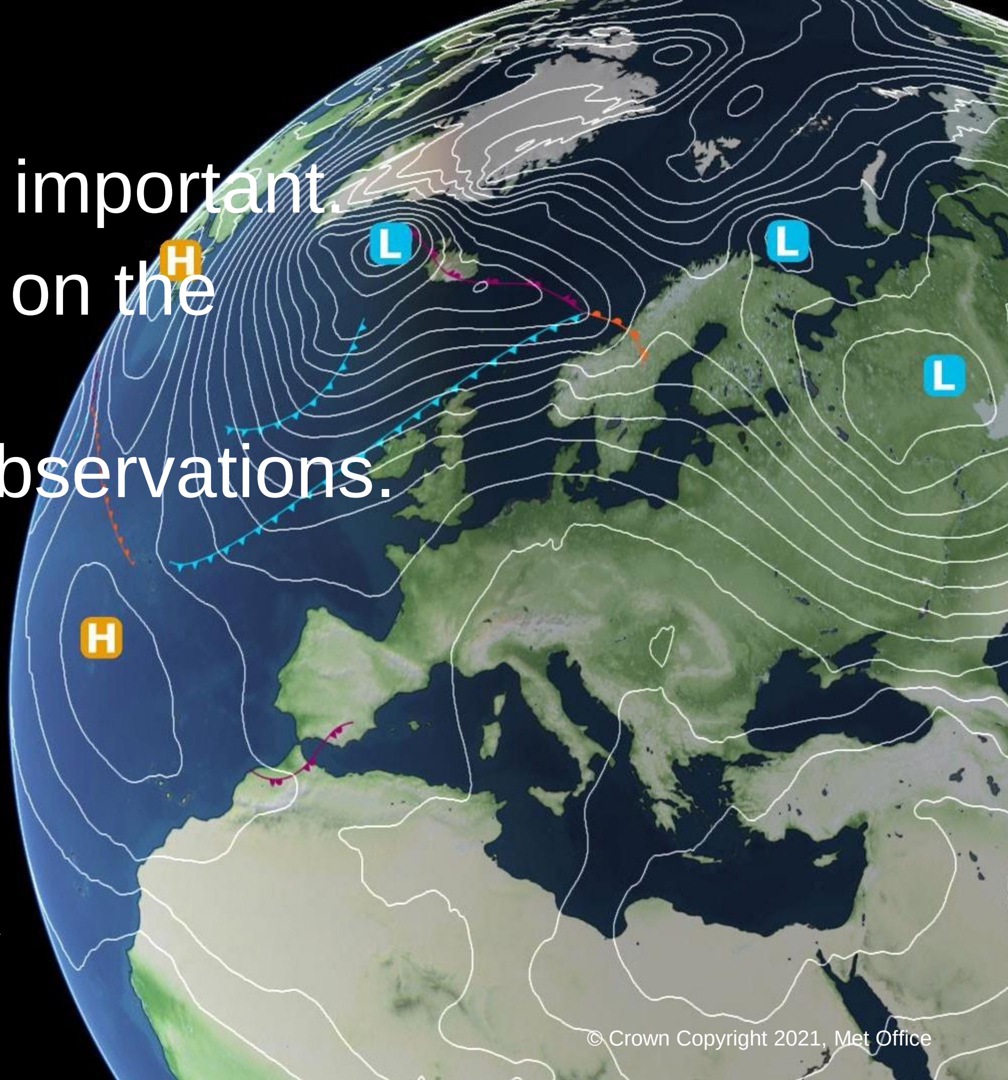
1. Scatterometer SCA follow-on mission to MetOp (ASCAT) starting 2025
2. Copernicus Sentinel expansion missions. CIMR Microwave radiometer, CHIME Hyperspectral imager
3. Retrieving high resolution soil moisture from Canada's RADARSAT Constellation Mission (RCM) Synthetic Aperture Radar(SAR).
4. GNSS-R sensitivity to soil moisture on Nano satellite platforms (C.Köpken-Watts 12:25 Monday, GNSS-RO K. Bathmann Thursday 16:00 and GNSS slant delay R. Randriamampianina Friday 15:00)
5. Destination Earth (DestinE) : ECMWF, ESA & EUMETSAT aim to create a "digital twin" Earth simulation system using artificial intelligence and drawing on advances made in NWP.
6. Forward modelling techniques Machine learning & neural networks.
7. Citizen science (GROW) soil moisture measured with cheap sensors
    - Challenges with calibration, reliability, quality control
    - Benefits include increased coverage in interesting locations

Image Courtesy NASA JPL

c.charlton-perez@metoffice.gov.uk

Met Office

1. Land observations are important.
2. Requirements depend on the application.
3. Bright future for land observations.



Thank you for your time and attention!

Questions?

c.charlton-perez@metoffice.gov.uk