Toward assimilation of satellite soil moisture products over Europe

William A. Lahoz[1], Tove M. Svendby[1], Alexandra Griesfeller[1]

[1] NILU, Kjeller, Norway (wal@nilu.no)

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Work done within the ESA CCI Soil Moisture Project

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To not…

« A system that makes no errors is not intelligent »

« Risk Savvy », Gerd Gigerenzer

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Outline

- Information: satellite data & model data
  - Satellite data: AMSR-E (VUA-LPRM), ASCAT (TU-Wien), SMOS (SMOS data centre) – focus on July 2011
  - Model: SURFEX (v7.1)
  - Scaling satellite data
  - Combine: land surface data assimilation, DA (NILU EnKF system)
- DA experiments
  - Self-consistency tests; estimate of observational errors
  - Tests of methodology – observation & model errors
- First results
- Conclusions & future work

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Overarching objective of data assimilation effort

- Provide the best estimate of soil moisture fields, including error characteristics, and use this information to improve our understanding of the hydrological cycle over land. In particular, to improve:

  - Weather forecasts
  - Hydrology forecasts
  - Simulation of the hydrological cycle over land, for weather and climate studies
  - Monitoring of the hydrological cycle over land

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Observation types

- Observing land component of Earth System - characteristics:
  - Heterogeneous; non-Gaussian errors; non-linearity; relatively long memory; 1-D (affects way we treat information about the land)

- Observation types & spatio-temporal characteristics
  - Remote sensing: satellites

    - Global coverage: good representativity for a large area
    - Relatively low temporal resolution: 2 obs/day for a LEO
    - Relatively low spatial resolution: footprint of ~40 km for SMOS

  - In situ: point-based measurements

    - Local coverage: poor representativity for a large area
    - Relatively high temporal resolution: typically minutes
    - Relatively high spatial resolution: typically metres

Observations have errors: random, systematic, representativeness

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Issues with soil moisture observations

- Different spatial scales:
  - In situ data: point measurements
  - Satellite data represent an integrated area, resolution ~40-50 km

  Error of representativeness (horizontal)

- Microwave measurements only sensitive to first cm of surface layer
  - ~ 5 cm depth L-band (SMOS)
  - ~ 1 cm depth C-band (ASCAT, AMSR-E)
  - ~ few mm depth X-band (AMSR-E)

  In situ network (e.g. Norway) measures soil moisture at 10 cm

What is being measured?

Match scales and integrated quantities: model, DA

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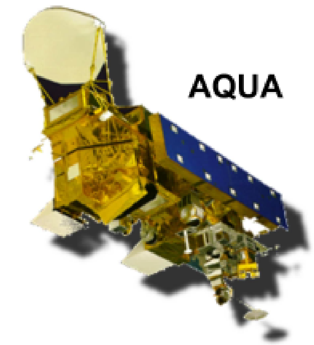
Satellites

EOS Aqua

AMSR-E passive microwave (radiometer), 6 frequencies: 6.9 - 89.0 GHz, spatial resolution: 74 - 10 km, soil moisture: X-/C-band (6.9/10.5 GHz, up to 30 km resolution)

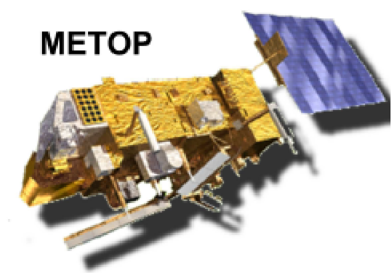
few mm



Metop-A

ASCAT: active microwave (radar), successor to ESA's ERS-1 and ERS-2, 5.26 GHz (C-band), spatial resolution: 25 km

~1 cm



SMOS: MIRAS passive microwave, 1.4 GHz (L-band), spatial resolution: 40 km

~5 cm

Courtesy
G. De Lannoy

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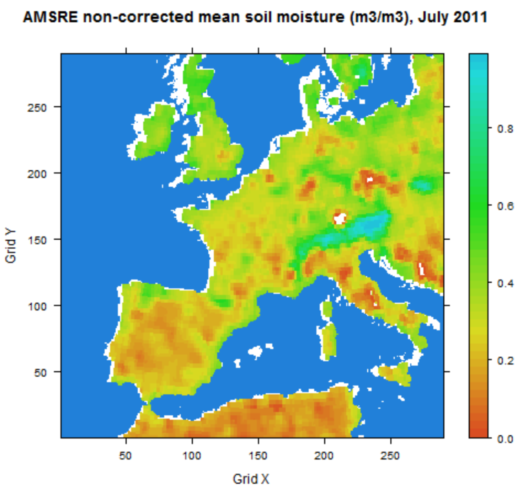
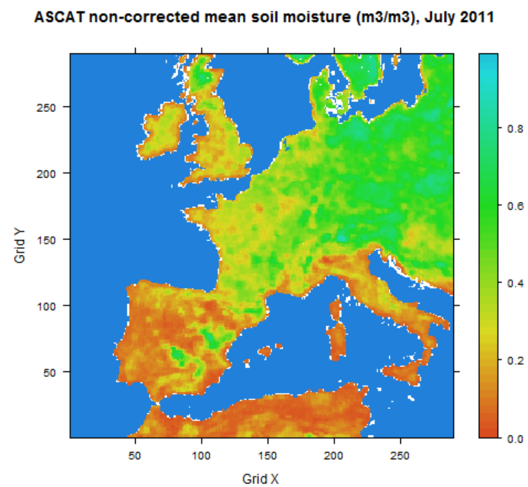
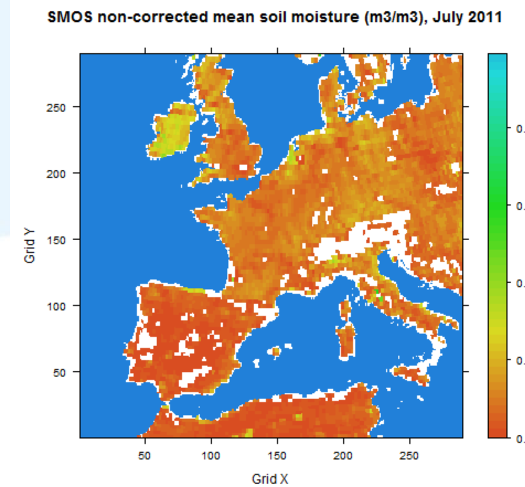
Reconcile measurements & model – focus on anomalies

Satellite data

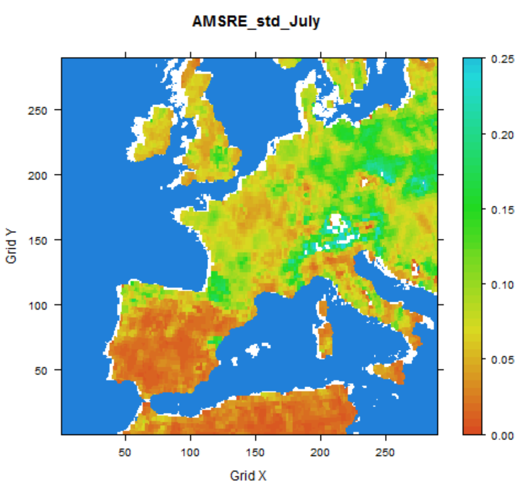
ASCAT converted to m^3m^{-3} using % -> (0,1)
Assumes max/min values are 100%, 0% (approx.)

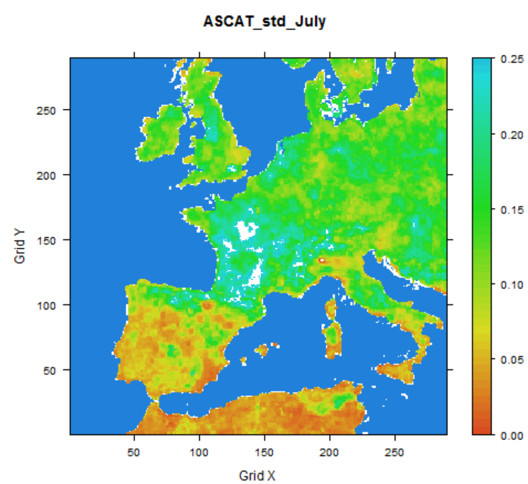


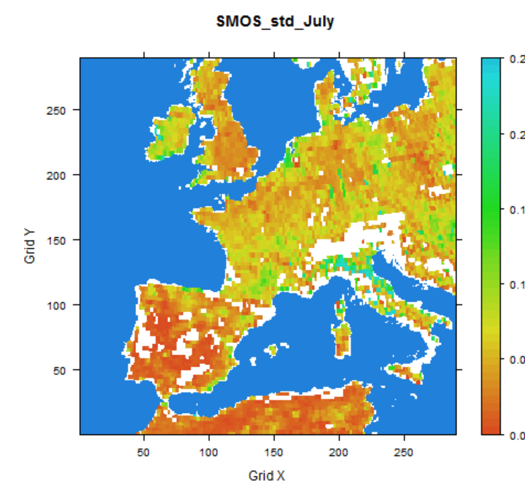




Satellite information – unscaled, July – top: mean; bottom: std







SMOS drier
ASCAT more variable

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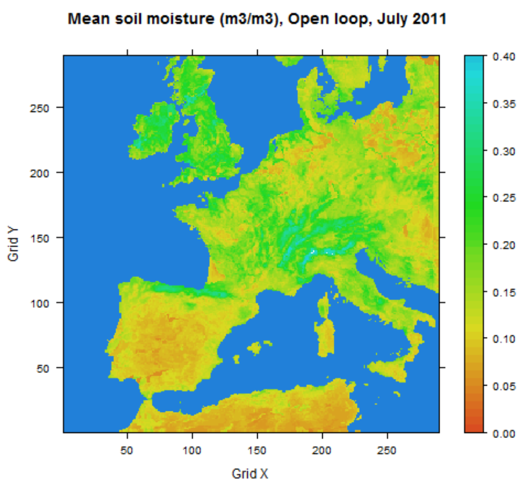
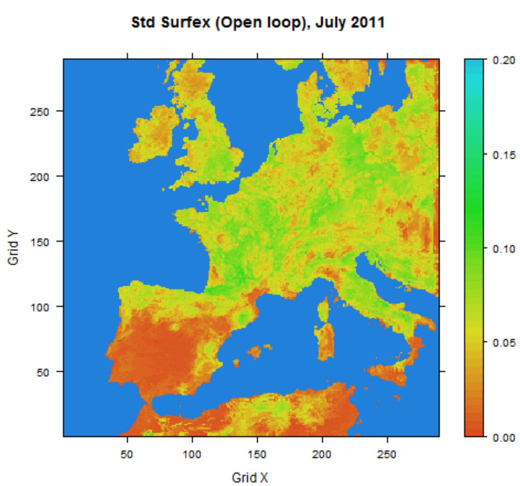
Model data





Model – SURFEX (Le Moigne 2012): July – top: mean; bottom: std

Scale satellite data to model data – account for bias & variability:

Linear re-scaling (*Brocca et al., 2013*):

$$SAT_{RES} = \frac{\left[SAT - \mu(SAT)\right]}{\sigma(SAT)}\sigma(OBS) + \mu(OBS)$$

SAT : satellite; OBS : model

Satellite data: same mean & std as model over July 2011

Focus on satellite anomalies
Look at selected days & time series

N.B. CDF-matching inappropriate
length of time series is too short – future work

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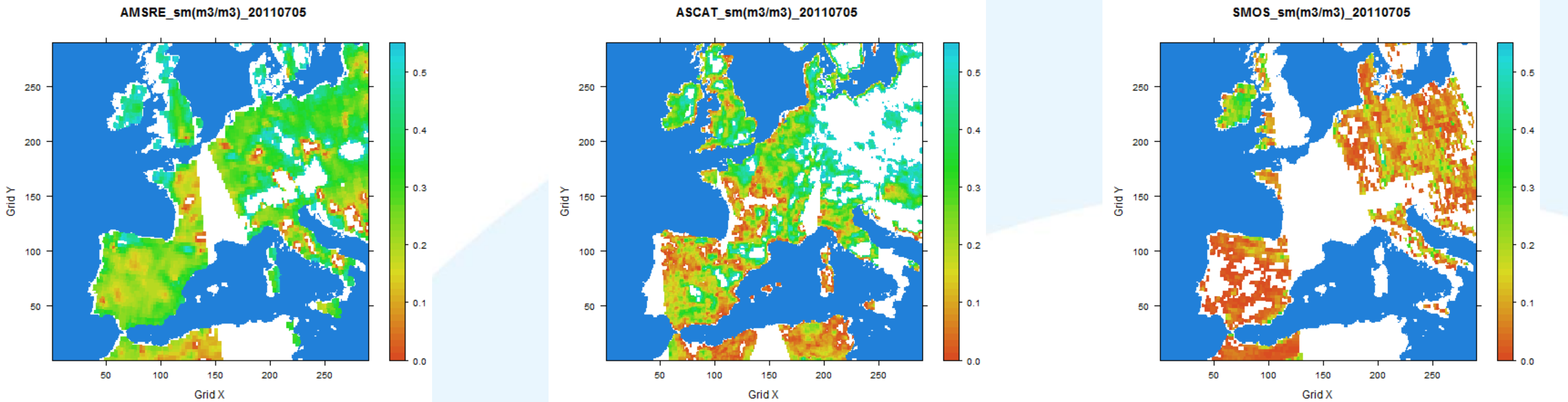
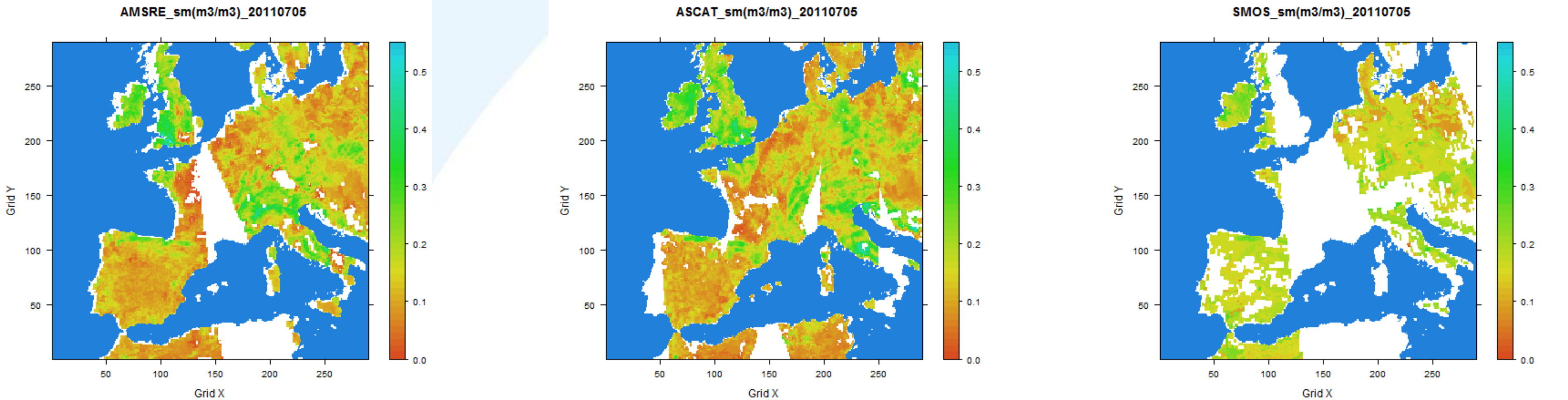
Scaling data



Satellite information 5 July – top: unscaled; bottom: scaled



Scaling: dries AMSR-E, ASCAT, moistens SMOS
White areas: either no data, or data off-scale

Data assimilation

Combine obs & model information + errors *Lahoz & De Lannoy, Surv. Geophys., 2014*

Focus on July 2011 – European domain – short period so care with stats

EnKF (variants) – use ensemble square root EnKF (*Sakov and Oke, 2008*)

- Model spin-up (1 month)
- Model forcing from WRF (NCAR FNL data) – check representation of precipitation
- Five ensemble members (can choose other sizes)
- Perturbation of superficial & mean volumetric water content - precipitation forcing available but not used; mean of ensemble = 0
- Scale observations to model (linear re-scaling; other options)
- Test observational errors (chi-square approach)
- Test system using self-consistency (O-F vs O-A differences)
- Test results against independent data (ISMN in situ data) – also ESA CCI data

Land DA results are preliminary & illustrative

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Tests

Observations: self-consistency tests; evaluation of errors Chi square approach applied to corrected satellite data

N = no. of obs (July); F = forecast; A = analysis:

Chi-sq(A) = (1/N) * SUM[(O-A)^2 / R] Chi-sq(F) = (1/N) * SUM[(O-F)^2 / R]

1. O-A differences should be smaller than O-F differences – self-consistency test; passed
2. Chi-sq values should be close to 1 – observational error information

SMOS (N=547431)

YERROBS=0.1 - Chi-sq(A) = 8.88
YERROBS=0.1 - Chi-sq(F) =64.45
YERROBS=0.3 - Chi-sq(A) = 2.86
YERROBS=0.3 - Chi-sq(F) = 6.79
YERROBS=0.6 - Chi-sq(A) = 1.11
YERROBS=0.6 - Chi-sq(F) = 1.69

AMSR-E (N=949842)

YERROBS=0.3 - Chi-sq(A) = 2.71
YERROBS=0.3 - Chi-sq(F) = 6.38

ASCAT (N=1007729)

YERROBS=0.3 - Chi-sq(A) = 2.72
YERROBS=0.3 - Chi-sq(F) = 6.45

SURFEX code - observational error defined as R = (YERROBS*COFSWI)^2

YERROBS, parameter set in input file: typically use 0.3

COFSWI=(W_{fc}-W_{wilt}) typical range 0.06- 0.09

Error associated with SMOS anomalies is in range 0.036 – 0.054 m^3m^{-3} when YERROBS=0.6

Consistent with a SMOS error of 0.04 m^3m^{-3}

Kerr et al., 2010

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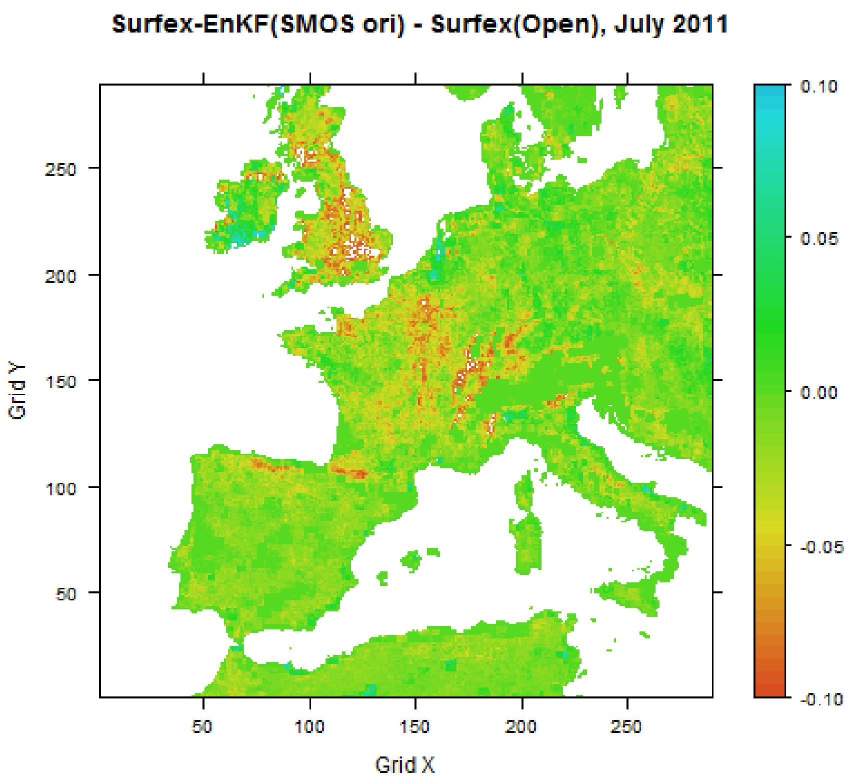
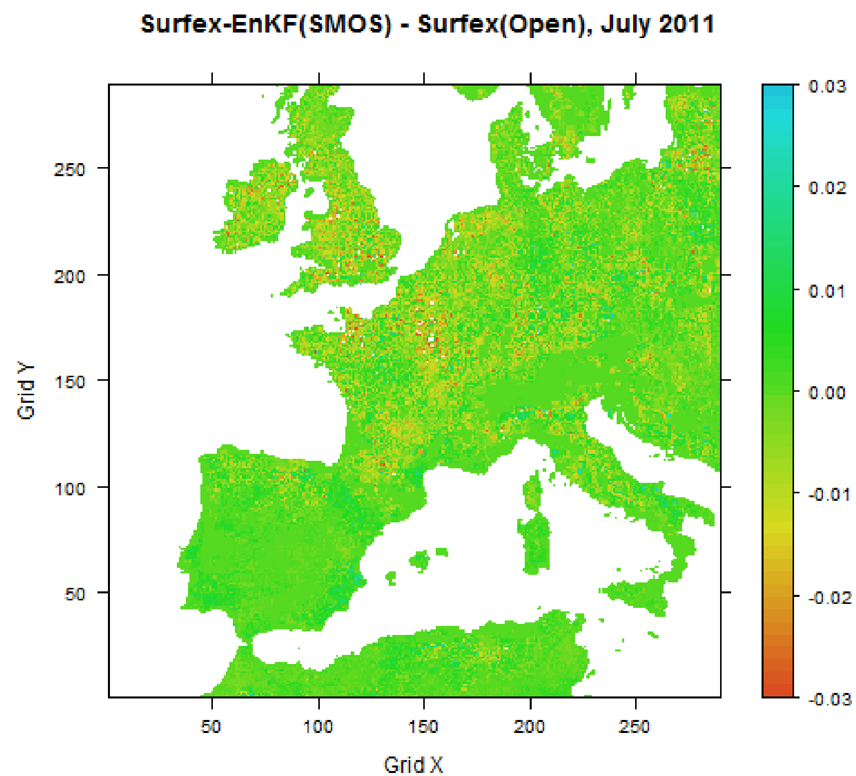
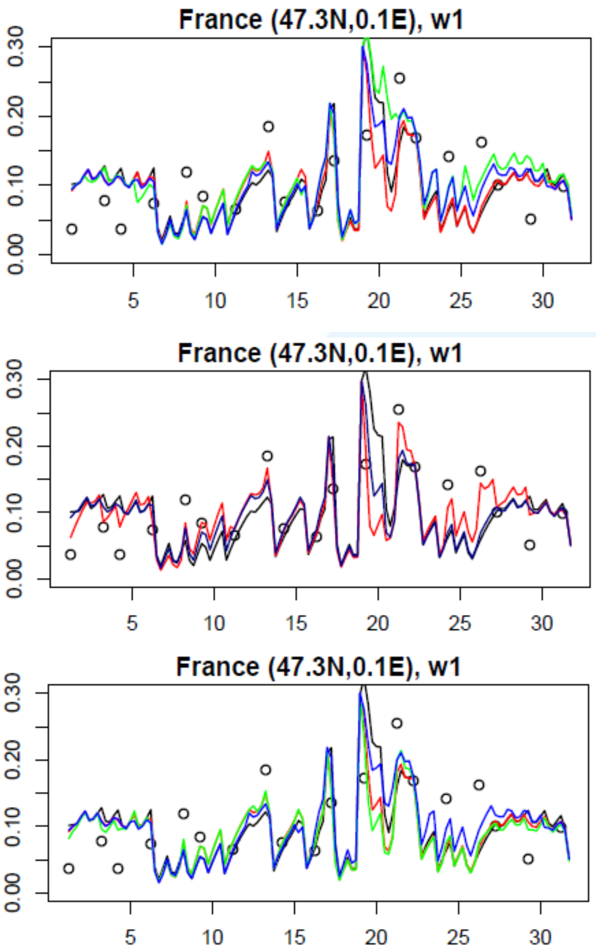
July, SMOS, Differences: analyses – model
Left: unscaled SMOS; Right: scaled SMOS





Regions of larger impact in unscaled version replicated in scaled version - e.g., France/Germany/England

DA tests: analyses, model, observations (scaled)
Location: nr. Tours, France



w1: superficial volumetric water content, m^3m^{-3}
YERROBS = 0.3

SMOS, open loop, EnKF-SMOS, EnKF-AMSRE, EnKF-ASCAT

YERROBS = 0.1, 0.3 Increase observational error

SMOS, open loop, EnKF-Y01, EnKF-Y03

Larger ensemble perturbation – SMOSp
Increase model error

SMOS, open loop, EnKF-SMOS, EnKF-SMOSp, EnKF-ASCAT

- AMSR-E wetter fields
- SMOS drier fields
- Impact of obs/model error

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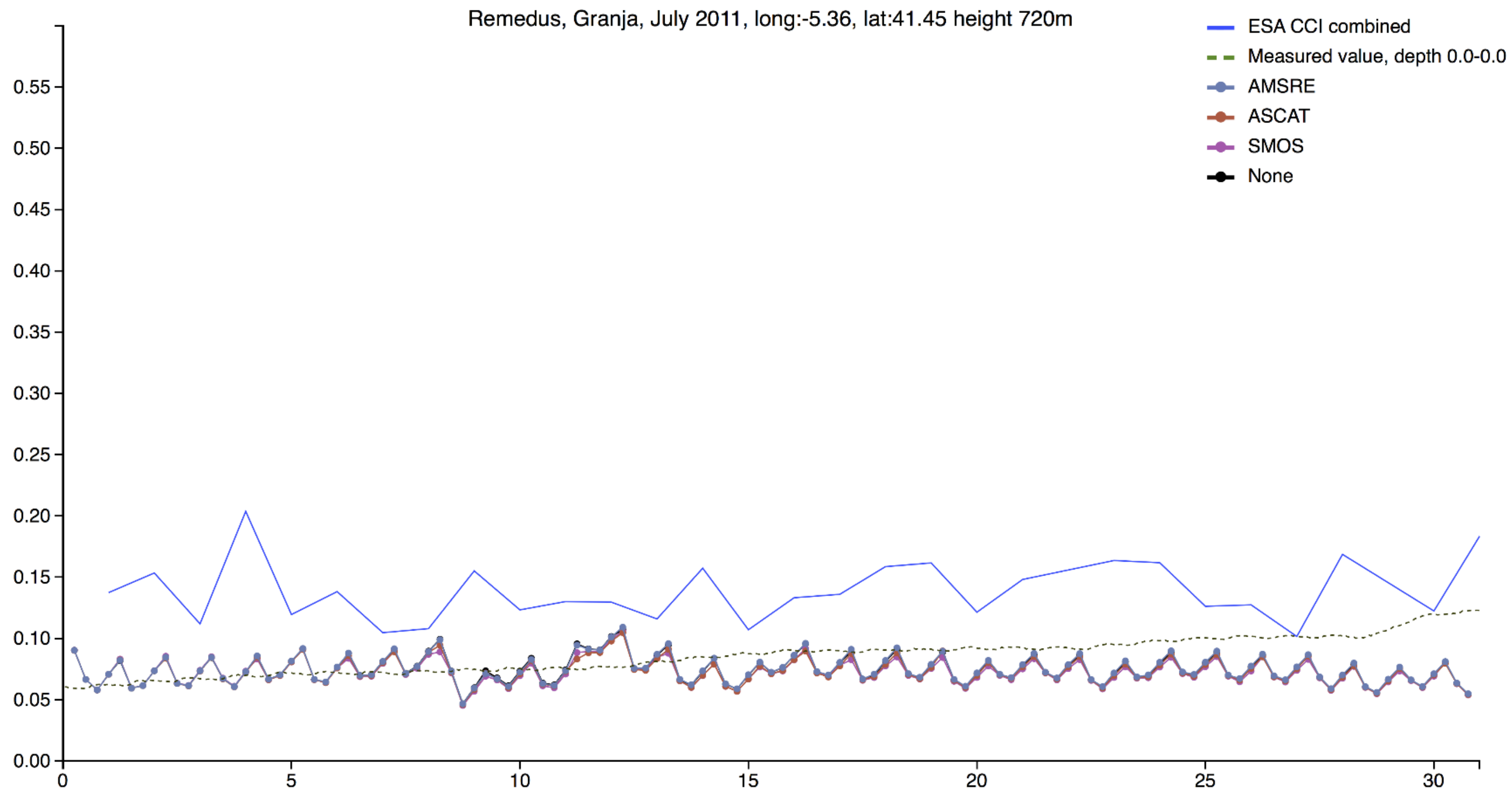
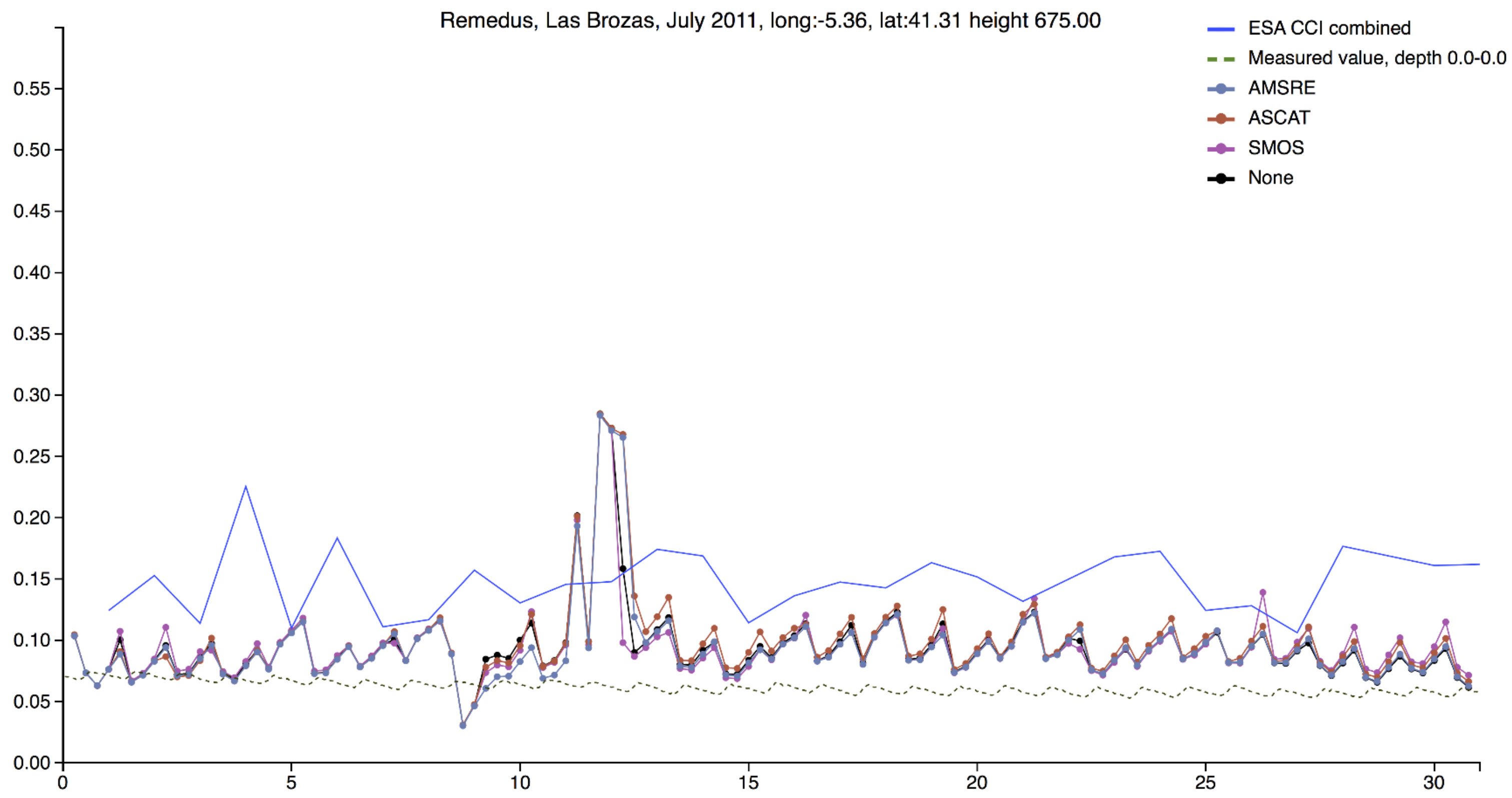
July

Test v independent data
Time series: analyses vs ISMN data – July 2011
Thanks Morgan Kjølerbakken



REMEDHUS - Granja 41.31N, 5.36W 720 masl

REMEDHUS - Spain



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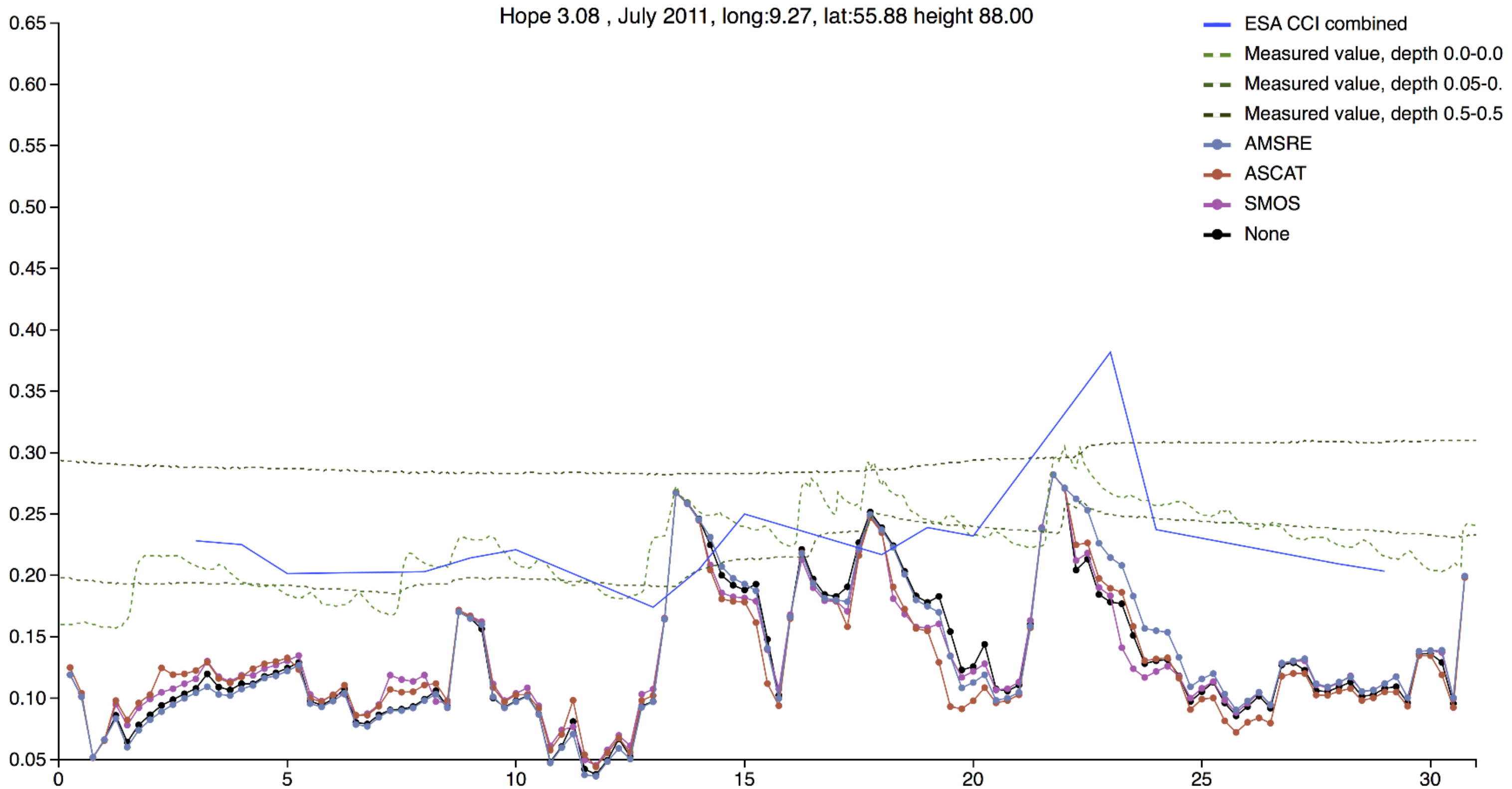
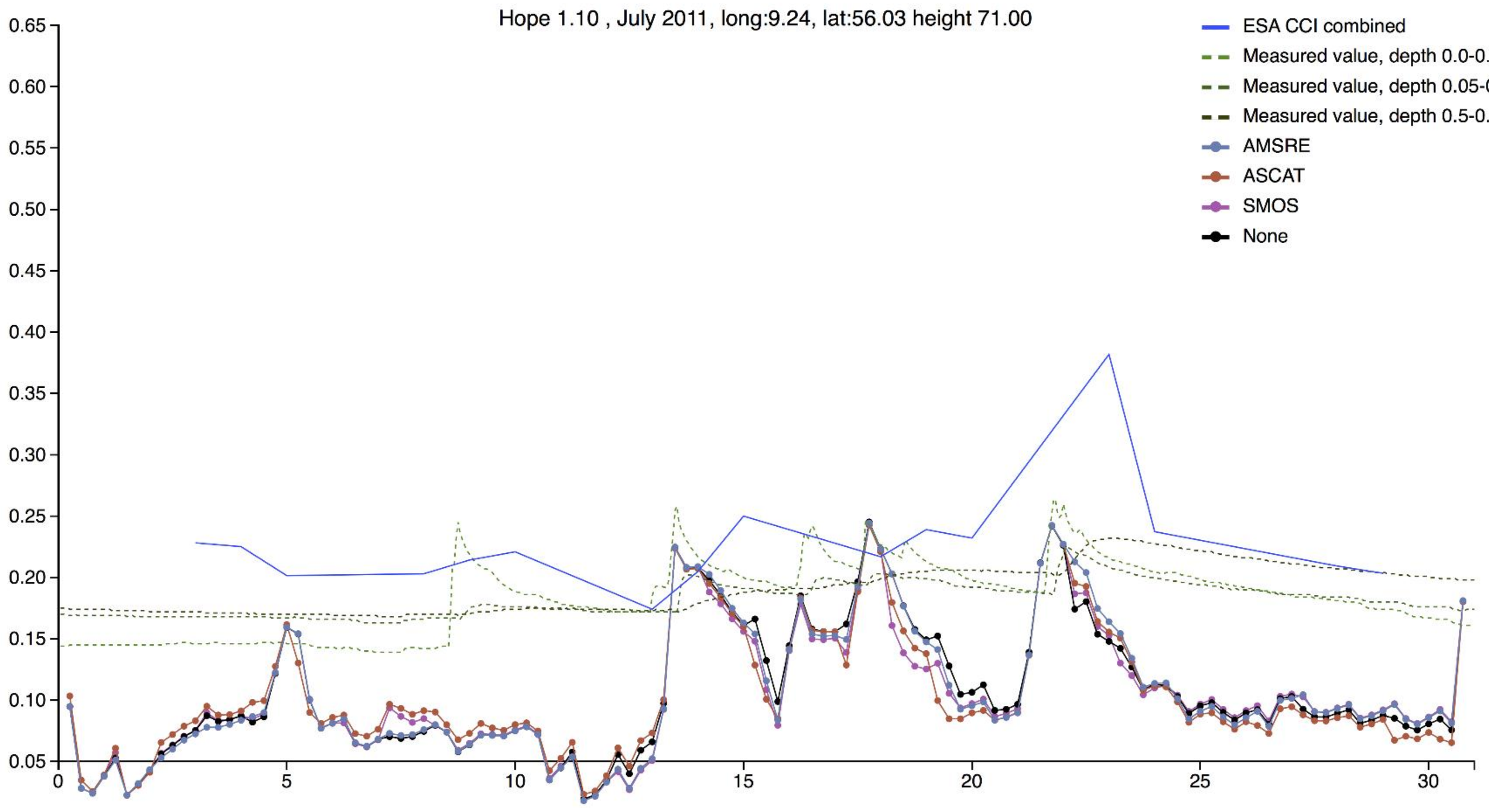
REMEDHUS – Las Brozas 41.45N, 5.36W 675 masl

REMEDHUS - Spain



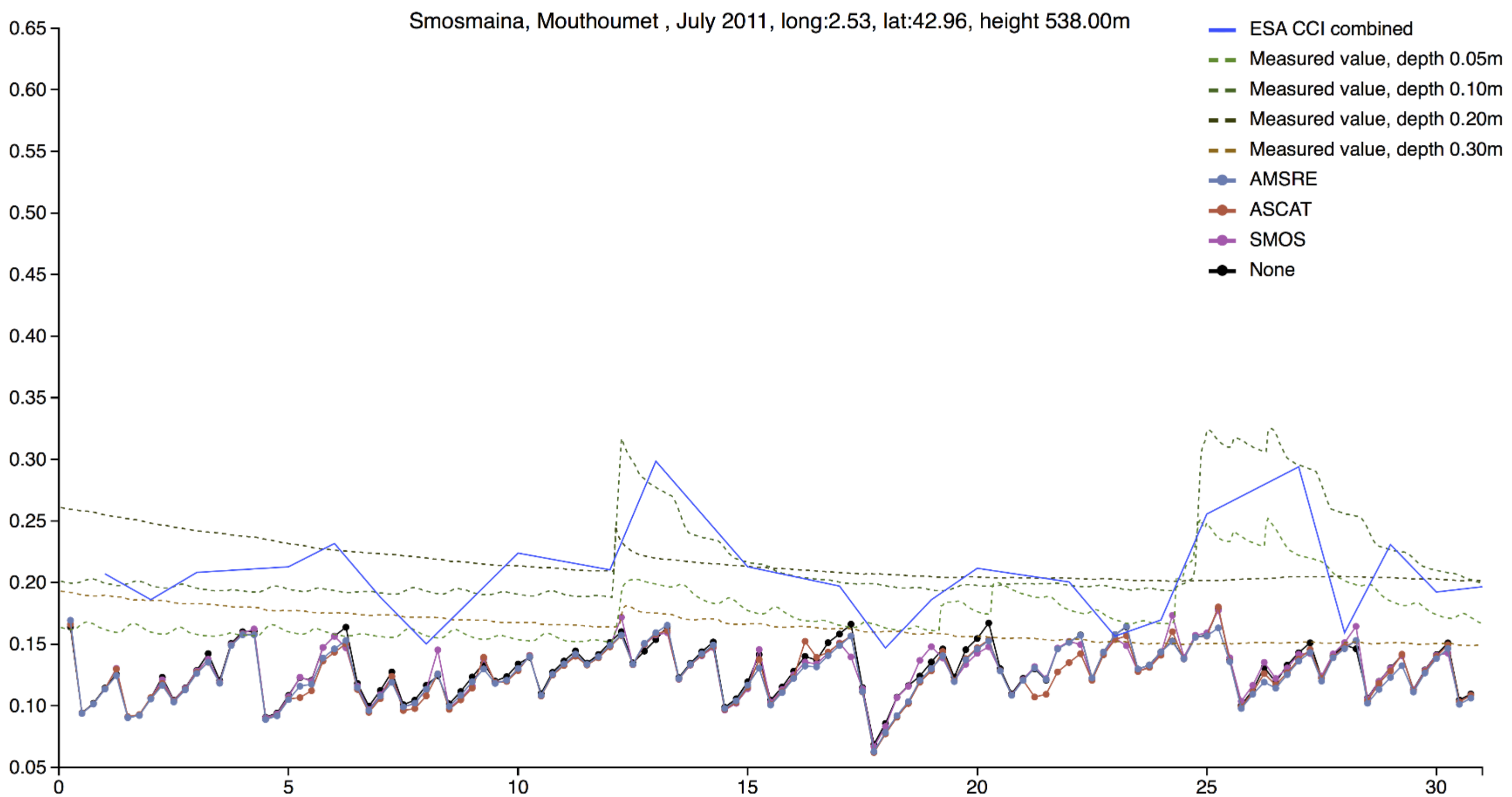
Hobe – site 55.88N, 9.27E 88 masl

HOBE - Denmark



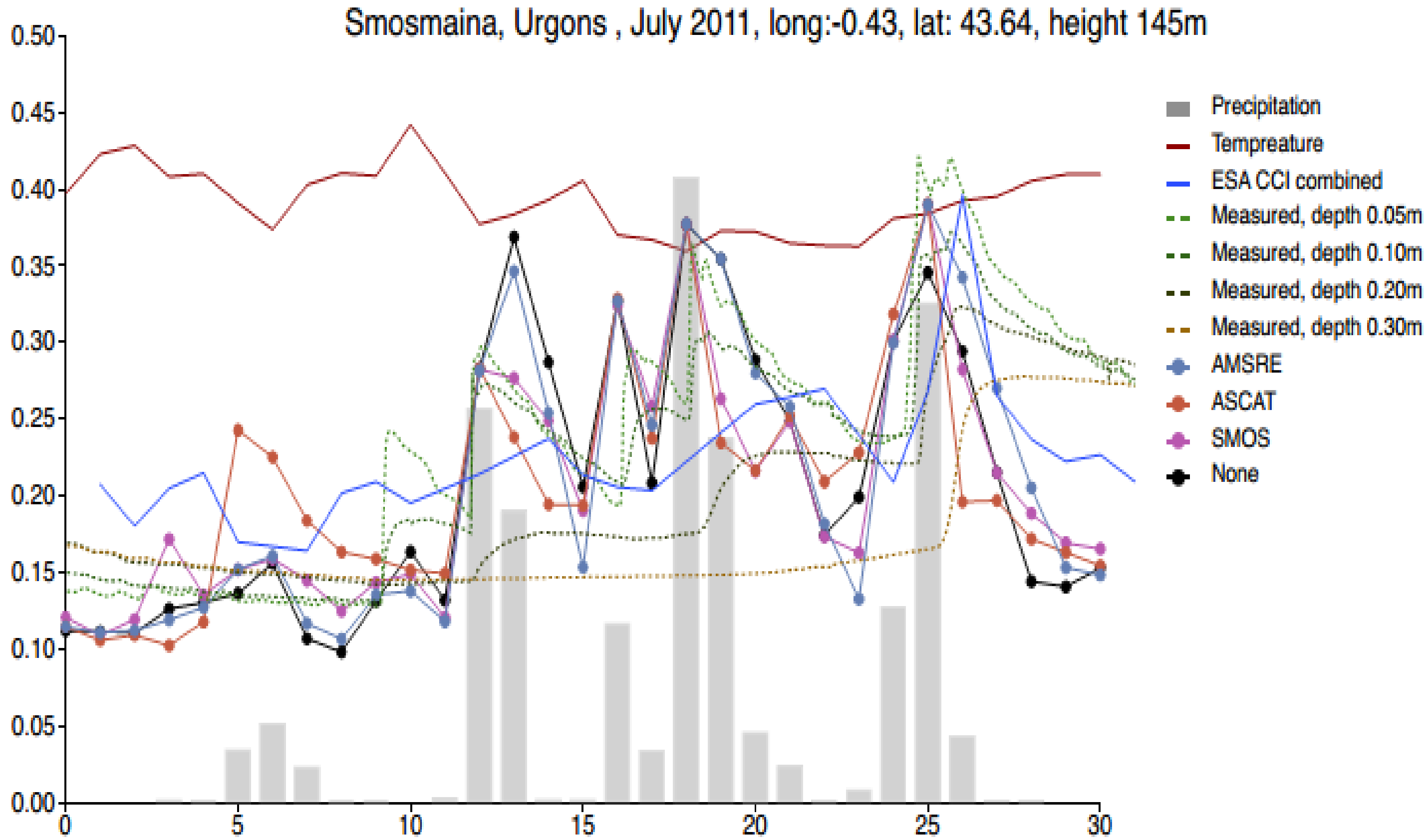
Hobe – site 56.03N, 9.24E 71 masl

HOBE - Denmark



SMOSMANIA – Mouthourmet, 42.96N, 2.53E 538 masl

SMOSMANIA - France



SMOSMANIA - Urgons 43.54N, 0.43W 145 masl

SMOSMANIA - France

Conclusions

- Rescaling of satellite data -> anomalies wrt SURFEX model
- Forcing of WRF realistic – precipitation consistent with soil moisture
- Assimilation of satellite anomalies – done, but time period short
- Self-consistency tests (O-A, O-F, obs/model error) – PASSED
- Information on satellite measurement errors - CONSISTENT
- Comparison with independent data – PATTERNS AGREE – BIAS?
- Useful information in assimilated products – ADDED VALUE

Future work

- Extend time period, ideally at least 1 year (trends) – THEN:
- Use CDF-matching (or another method)
- Assimilate the satellite datasets (AMSR-E, ASCAT, SMOS) singly/together
- Assimilate ESA CCI combined data (self-consistency)
- Evaluate analyses with ISMN in situ data & ESA CCI soil moisture datasets – data now available

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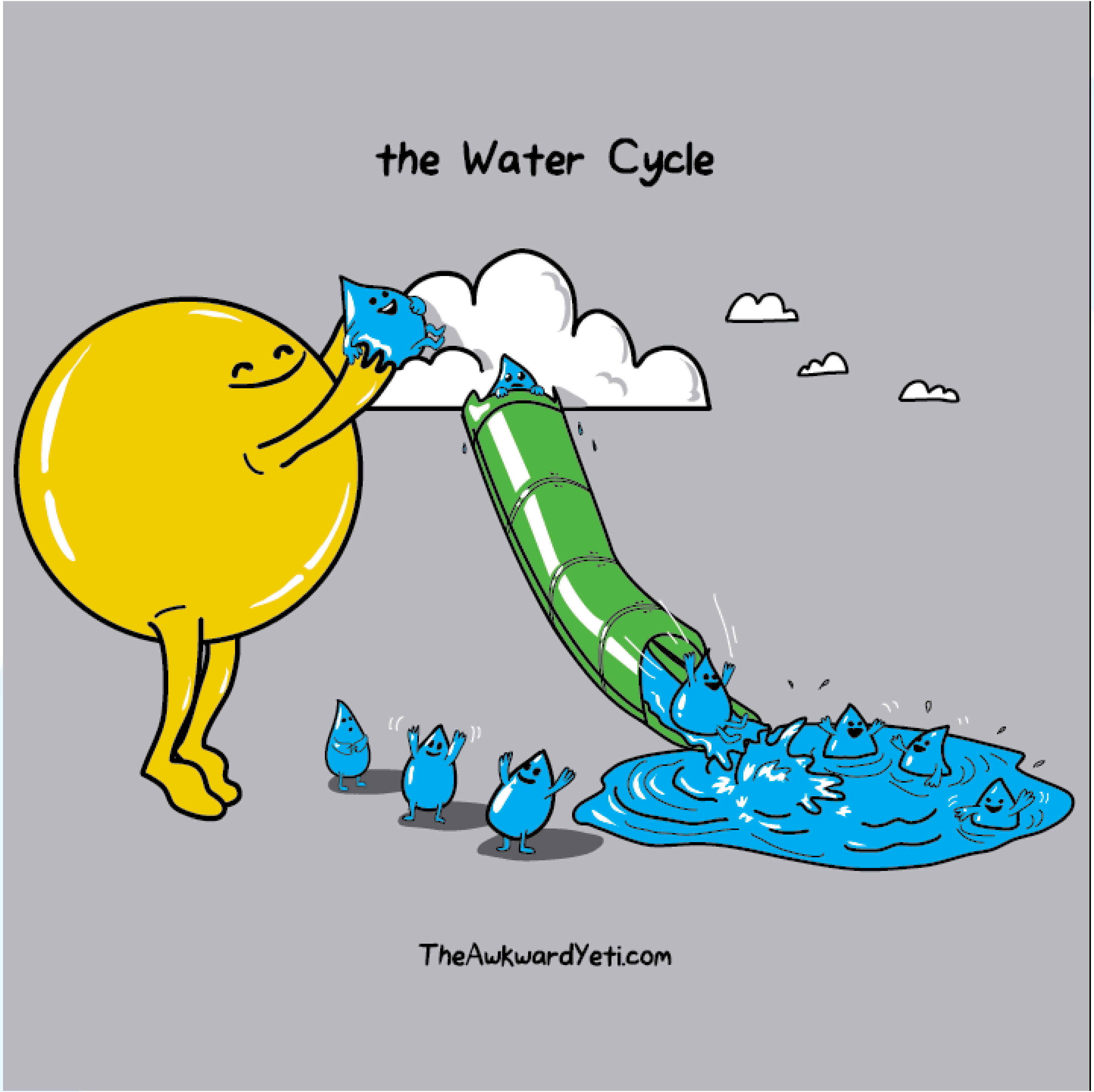

the Water Cycle
TheAwkwardYeti.com