Soil moisture monitoring for food security in Africa

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EUMeTrain Environment Week 2016

Session 2

April 12th, 2016 - 8 UTC

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Zentralanstalt für
Meteorologie und
Geodynamik

Hello!

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Motivation

- There are 795 million undernourished people in the world today.
- That means one in nine people do not get enough food to be healthy and lead an active life.
- Hunger and malnutrition are in fact the number one risk to health worldwide — greater than AIDS, malaria and tuberculosis combined.

Facts and pictures from http://www.wfp.org/

Motivation

What causes hunger?

There are many reasons for the presence of hunger in the world and they are often interconnected. Here are six that we think are important:

- **War and displacement**
- **Climate and weather**

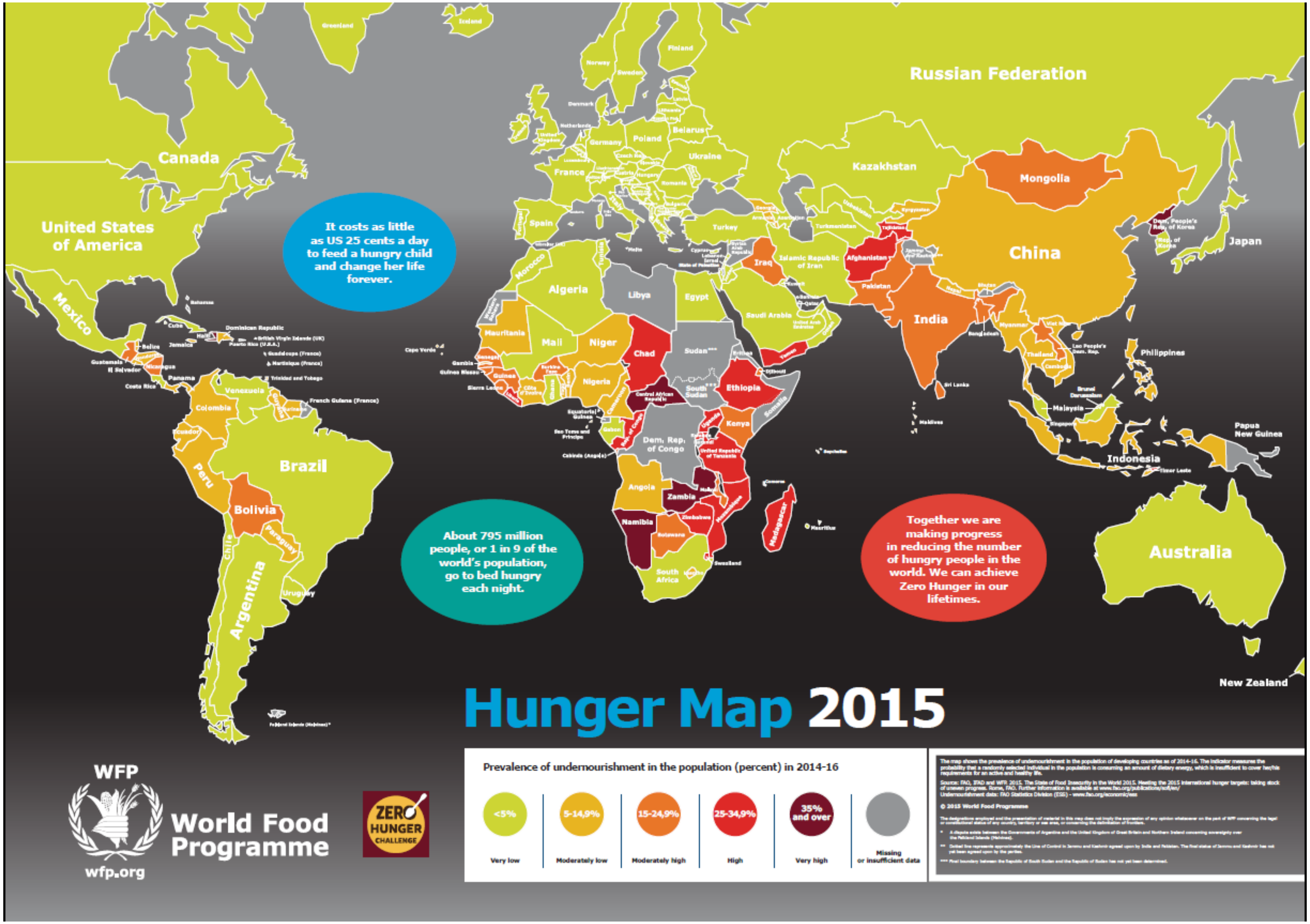
  Natural disasters such as floods, tropical storms and long periods of drought are on the increase -- with calamitous consequences for the hungry poor in developing countries.

  Drought is one of the most common causes of food shortages in the world. In 2011, recurrent drought caused crop failures and heavy livestock losses in parts of Ethiopia, Somalia and Kenya. In 2012 there was a similar situation in the Sahel region of West Africa.

  In many countries, climate change is exacerbating already adverse natural conditions. Increasingly, the world's fertile farmland is under threat from erosion, salination and desertification. Deforestation by human hands accelerates the erosion of land which could be used for growing food.
- **Food wastage**
- **Unstable markets**
- **Poverty trap**
- **Lack of investment in agriculture**

Facts and pictures from http://www.wfp.org/

Motivation



Facts and pictures from http://www.wfp.org/

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Overview

- How to measure soil moisture by satellites
- Combining measurements and model data
- Drought monitoring & forecasting
- Conclusions & outlook

How to measure soil moisture by satellites


© http://www.gfz-potsdam.de

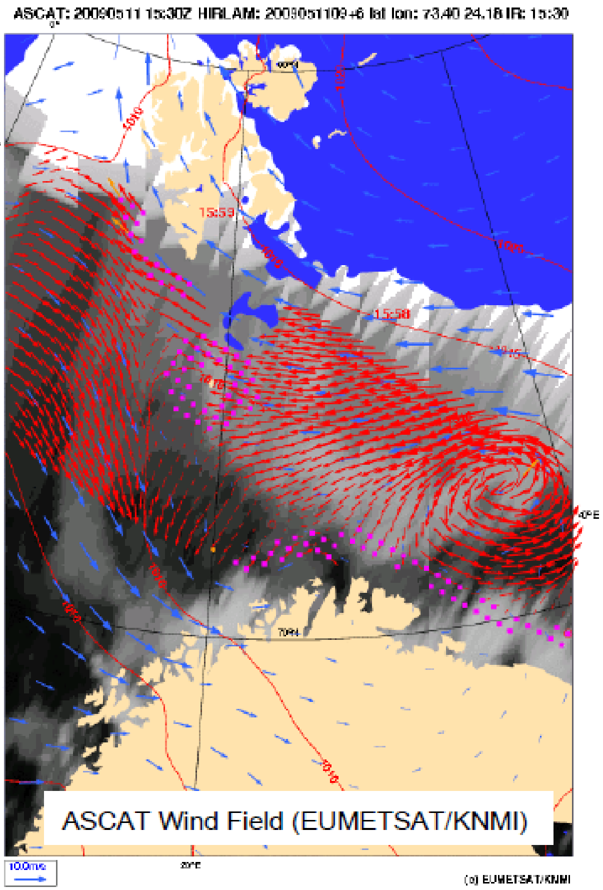
METOP-A: © http://www.russianspaceweb.com

© http://www.ahabc.de

How to measure soil moisture by satellites

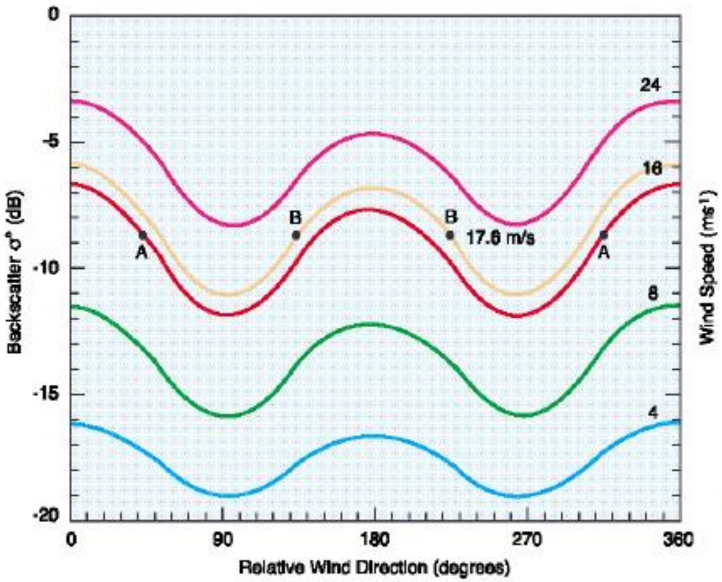
What are Scatterometers?

- Scatterometers measure the backscattering coefficient σ^0 with a high radiometric accuracy
- Designed to monitoring wind fields over the oceans
  - Assimilated operationally by meteorological services
- Sampling characteristics
  - High temporal resolution
  - Spatial resolution in the order of tens of kilometres
  - Several look directions



Principle of Wind Measurement

- Microwaves are scattered by the water surface
  - No penetration into the water
  - Scattering primarily dependent on surface roughness



Gelsthorpe et al. (2000)

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How to measure soil moisture by satellites – active systems

European C-Band Scatterometers

- **ERS Scatterometer**
  - λ = 5.7 cm
  - VV Polarization
  - Resolution: 50 / (25) km
- **Data availability**
  - ERS-1: 1991-2000
  - ERS-2: since 1995
    - gaps due to loss of gyros (2001) and on-board tape recorder (2003)
  - Operations conflict with ERS SAR

- **METOP Advanced Scatterometer**
  - λ = 5.7 cm
  - VV Polarization
  - Resolution: 50 / 25 km
- **Data availability**
  - At least 15 years
  - METOP-A: since 2006

    METOP-B: since 2012

- temporal resolution: ~1.5 days
- Data availability: ~2 hours after the measurement

Daily global scatterometer coverage: ERS (left) and METOP (right)

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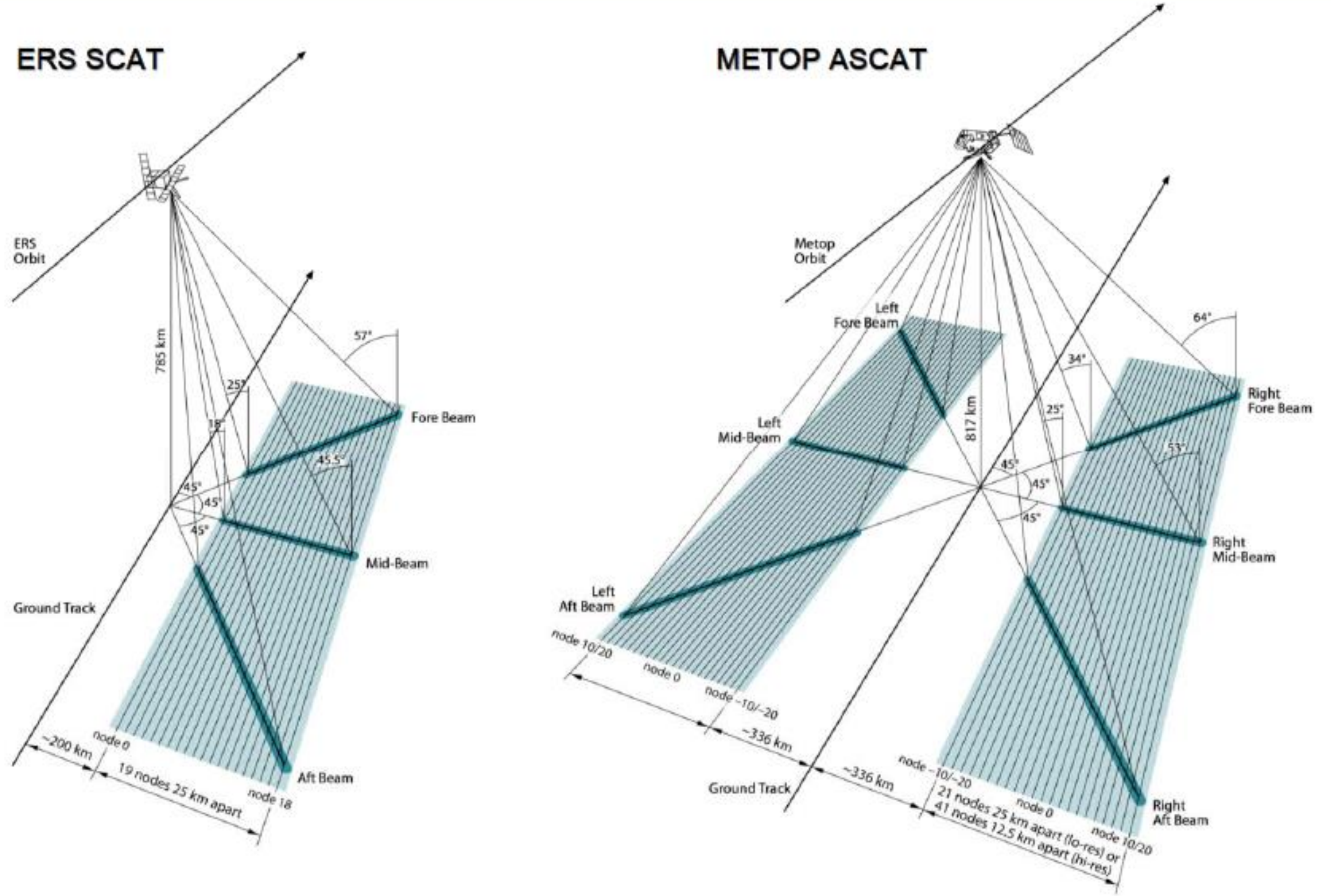
How to measure soil moisture by satellites – active systems



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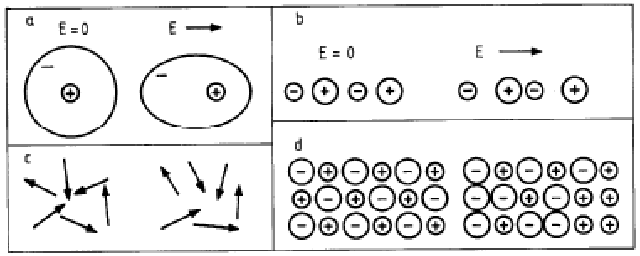
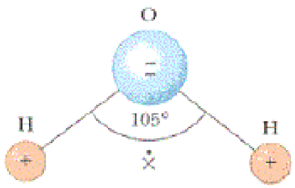
Polarisation of Media and the Importance of Water

- Polarisation mechanisms
  - Electronic (a)
  - Atomic (b)
  - Orientation (c)
  - Space charge (d)

Schanda (1986)



- Water is the only naturally abundant material with a permanent dipole moment leading to orientational polarisation



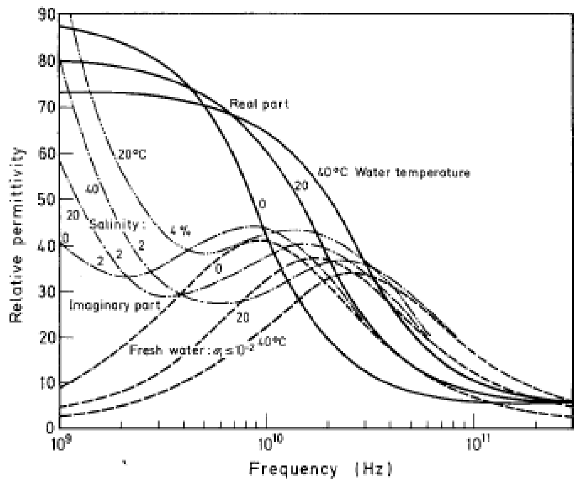
Dielectric Properties of Water and Soils

- The ability of matter to become polarized in the presence of an electric field is described by the permittivity ε

$$\varepsilon = \varepsilon_0 \varepsilon_r$$

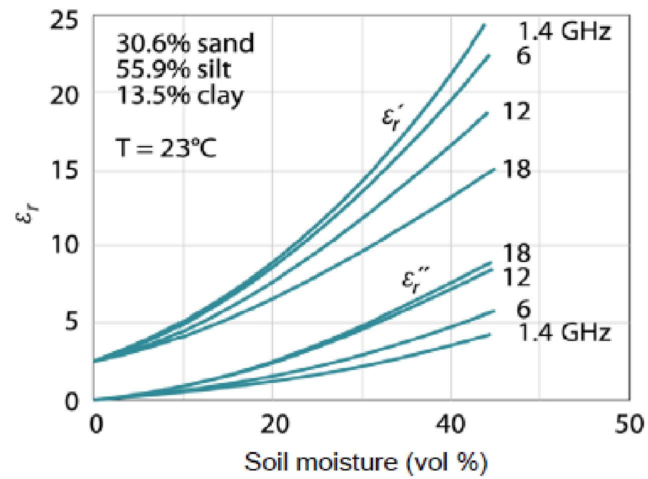
ε_0 … permittivity in vacuum (8.85 10^{12} As/Vm)
ε_r … Relative permittivity or dielectric constant

Water



Schanda (1986)

Soil



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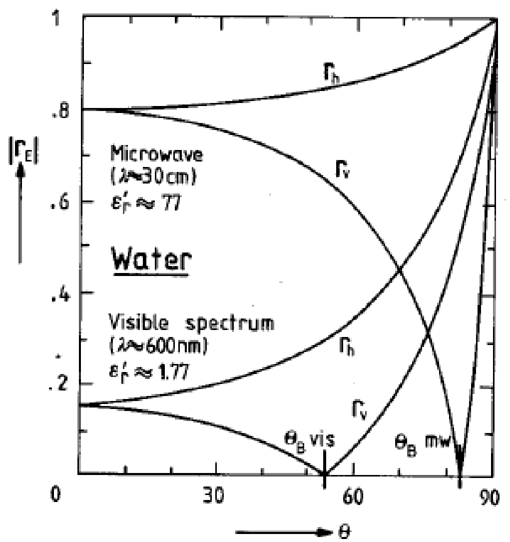
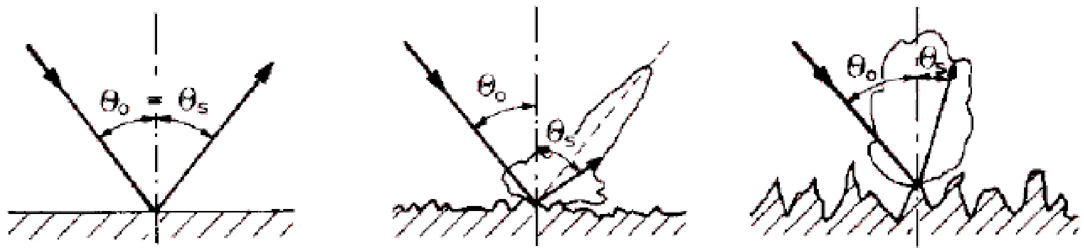
Surface Scattering

- Flat surfaces
  - Reflectivity accurately described by Fresnel's equations
  - A high dielectric constant means a high reflectivity
- Rough surfaces



Schanda (1986)



plane surface

medium rough surface

rough surface

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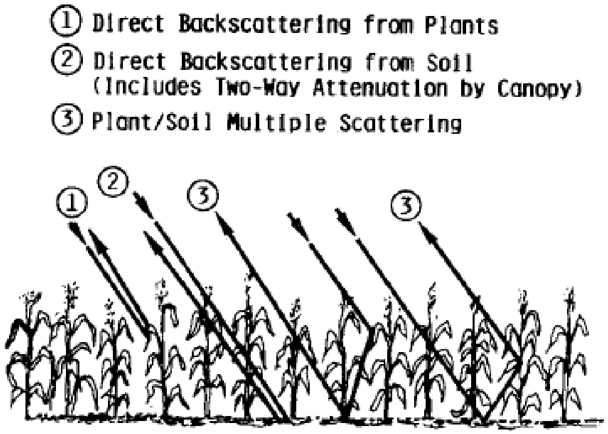
Backscatter from Vegetation

- Except for dense forest canopies, backscatter from vegetation is due to surface and volume scattering

$$\sigma^0_{veg} = \sigma^0_1 + \sigma^0_2 + \sigma^0_3$$

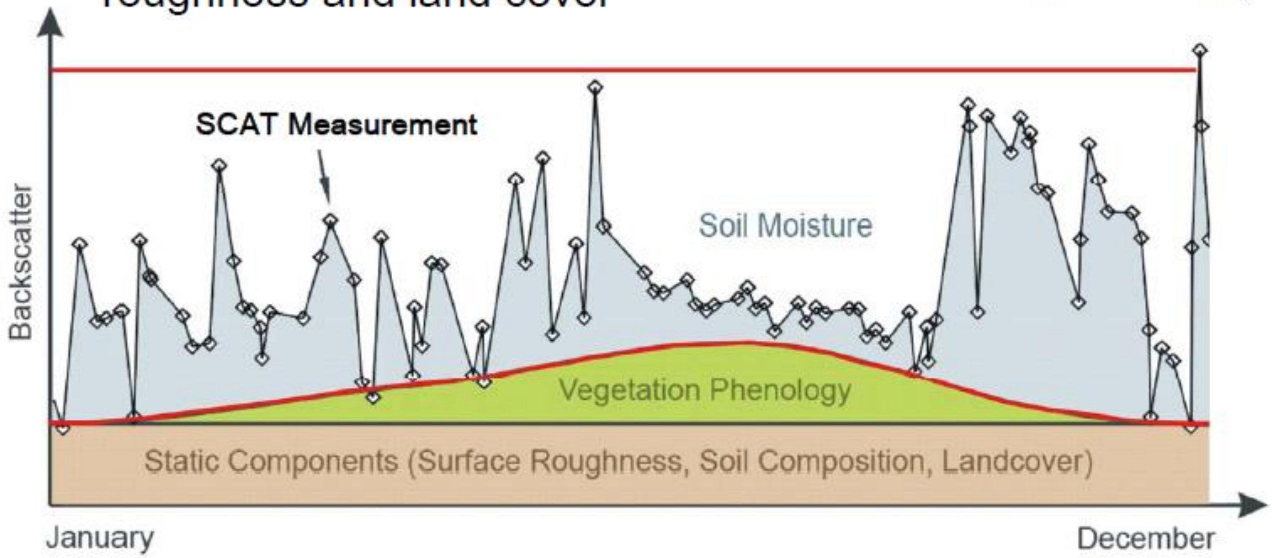


Ulaby et al. (1986)

TU Wien Change Detection Approach

- **Change detection**
  - Accounts indirectly for surface roughness and land cover

$$m_s(t) = \frac{\sigma^0(t) - \sigma^0_{dry}(t)}{\sigma^0_{wet}(t) - \sigma^0_{dry}(t)}$$



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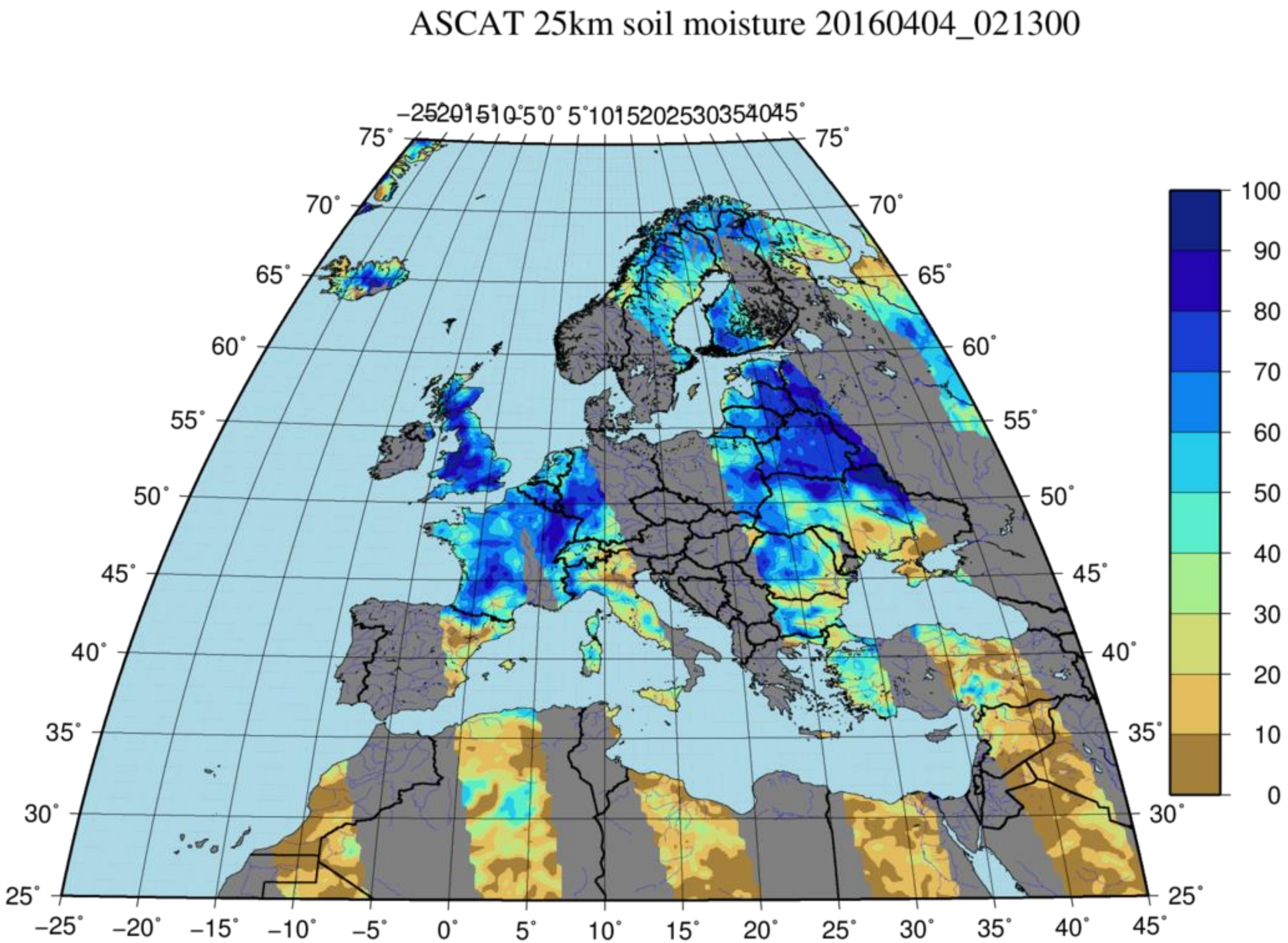
How to measure soil moisture by satellites – active systems



You can find this product on the HSAF webpage!

http://hsaf.meteoam.it/

http://www.zamg.ac.at/satweb/Kunden/HSAF_products/h07/

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Overview

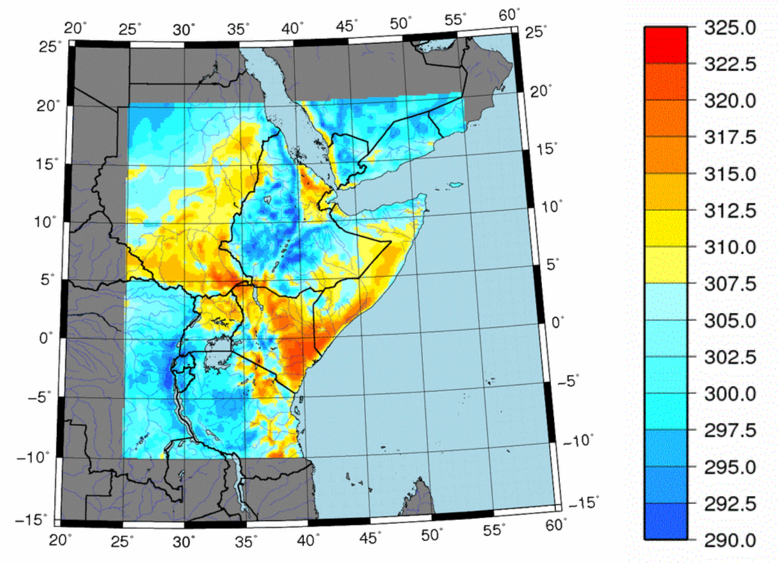
- How to measure soil moisture by satellites
- Combining measurements and model data
  - Dynamical downscaling & data assimilation
  - Statistical approaches (e.g. downscaling)
  - Common timeseries for past & future
- Drought monitoring & forecasting
- Conclusions & outlook

Dynamical Downscaling

Method

<u>ALADIN limited area weather numerical prediction model</u>

Forecast of the 2m temperature for 3.1.2009, 12UTC
(+36h forecast)



domain: 400x400 GPs, 60 levels
resolution: 8.5km grid
forecast range: 72h
coupling: IFS global model (~25km)
reference period: 1.1.2009 – 30.6. (31.12.) 2009
tuning: e.g. choose most suitable convection scheme
assimilation: simplified Extended Kalman Filter in SURFEX to include good soil moisture information in the forecast

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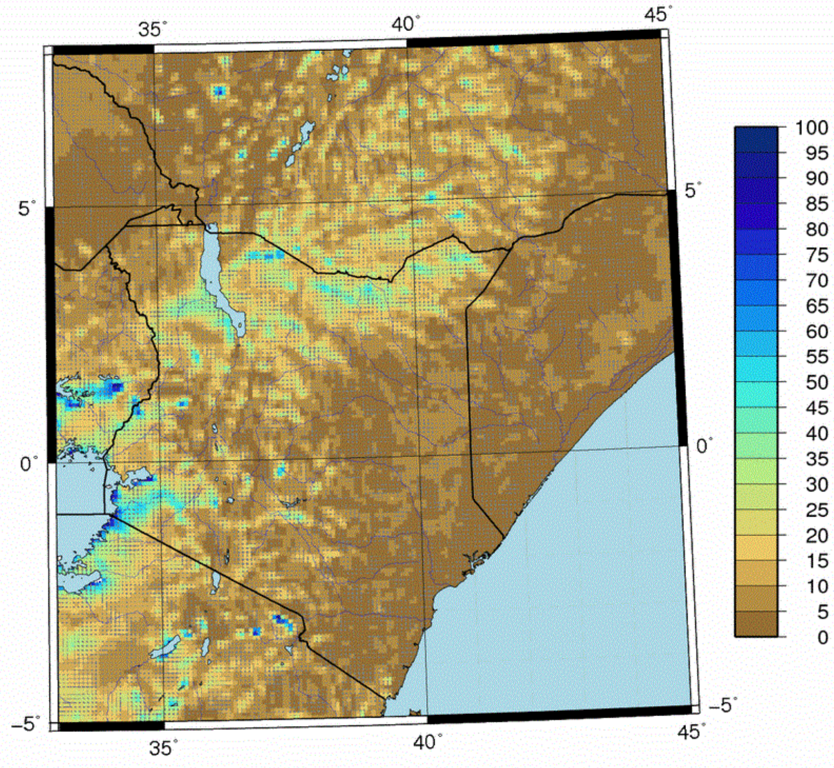
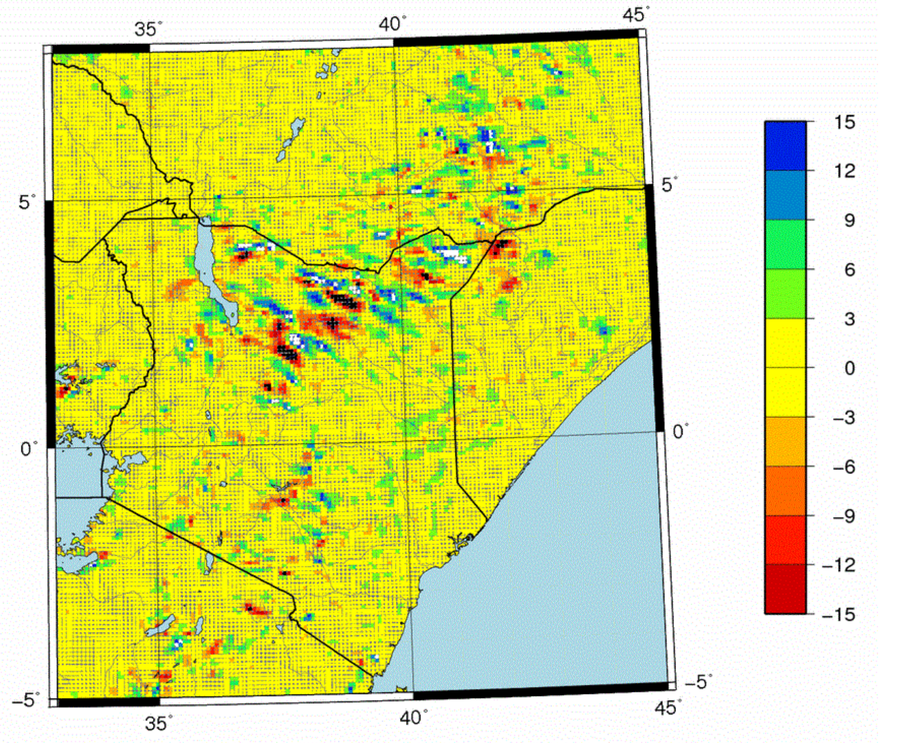
Dynamical Downscaling

Result

01.04.2009 00UTC +24h precipitation sum



ASCAT run [mm/24h]



difference ASCAT minus REF [mm/24h]

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Dynamical Downscaling

- Result

High-resolution regional **weather forecasts**, improved due to the assimilation of soil moisture data, can be used **for short time decisions** in agriculture, e.g. sowing and harvesting

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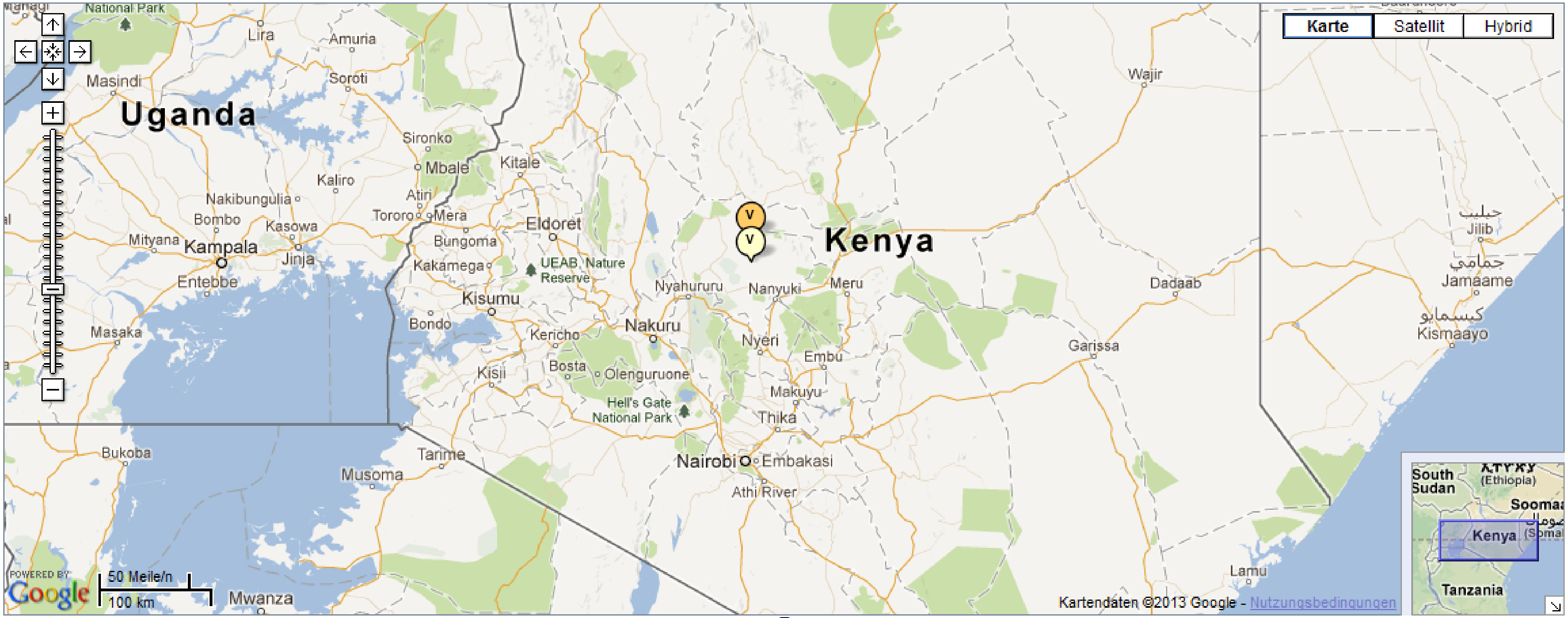
Statistical Downscaling



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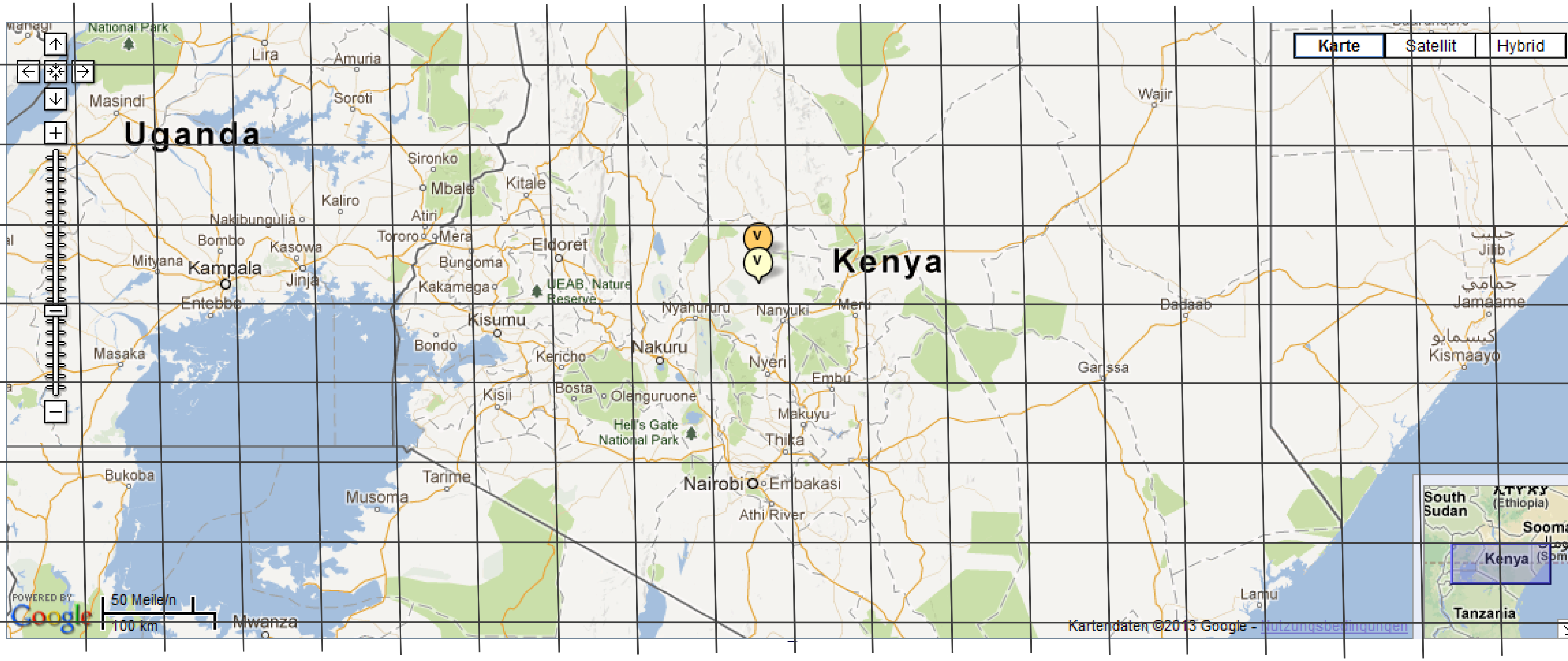
Statistical Downscaling



ECMWF
seasonal forecast grid

Statistical Downscaling

Input

Seasonal forecasts from ECMWF (http://www.ecmwf.int/)

IFS EPS System4
0.7° grid
51 ensemble members
+7 months forecast range
soil in HTESSEL is separated in 4 levels (7, 28, 100, 289cm) and 7 soil types

Reference forecasts from ECMWF

Ensemble made of historical high resolution analyses
0.125° grid (upscaled)
2001-2012

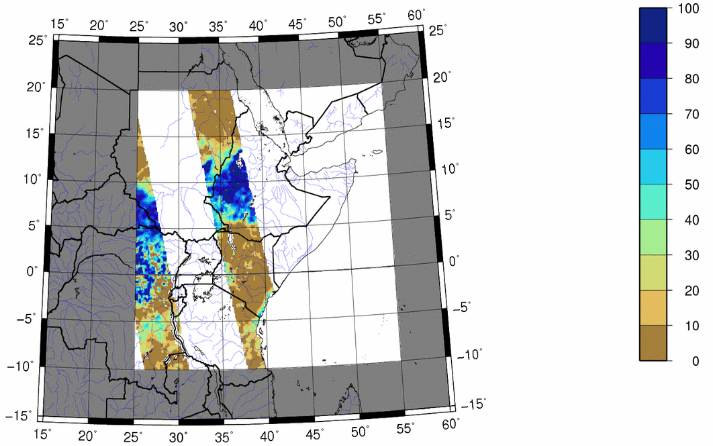
Statistical Downscaling

Input

COSMOS network in-situ measurements

2 stations in Kenya
hourly measurements [m3m-3]
15-30cm soil depth

02.07.2009, 19UTC



METOP-A ASCAT (Advances Scatterometer)

25km grid
provided by TU Wien

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Statistical Downscaling

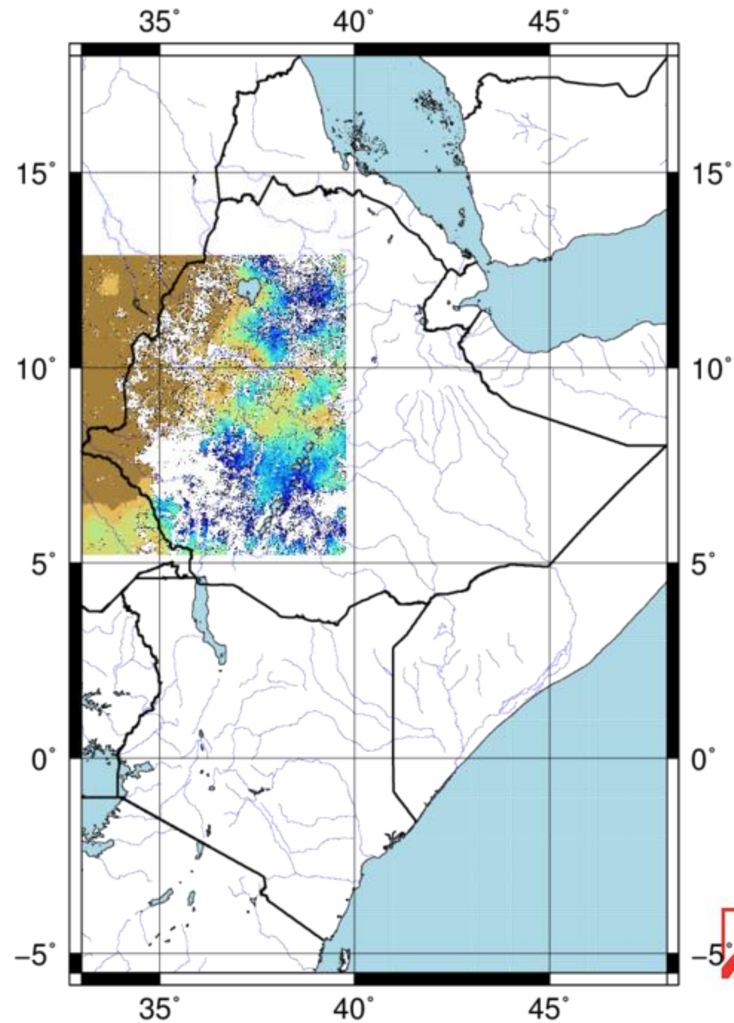
Input

<u>ENVISAT ASAR (Advanced Synthetic Aperture Radar)</u>

Spatial Resolution: approx1000m x 1000m
(Global Monitoring mode)
Swath Width: 400km
(Global Monitoring mode)
Microwave: C-band,
with choice of 5 polarisation modes
(VV, HH,VV/HH, HV/HH, or VH/VV)
Earth Topics: Landscape Topography, Snow and Ice , Ocean Currents and Topography)

using ASCAT-ASAR relationship
for downscaling (Wagner et al., 2008)

$$m_s^{1km}(t,x,y) = c_{ASAR}(x,y) + d_{ASAR}(x,y)m_s^{25km}(t)$$



12.04.2012

Statistical Downscaling

Method

2 steps

1. calibrate model forecasts with ASCAT data

2. downscale model forecasts with ASCAT-ASAR relation

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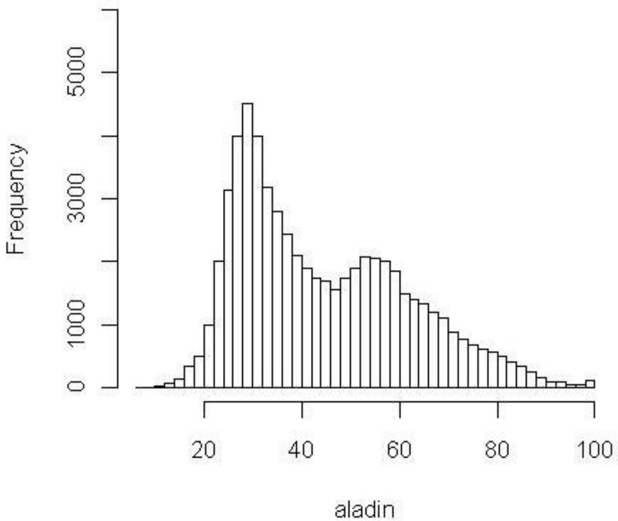
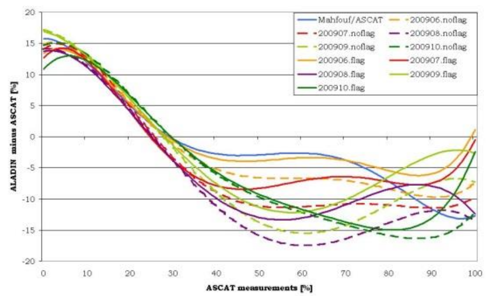
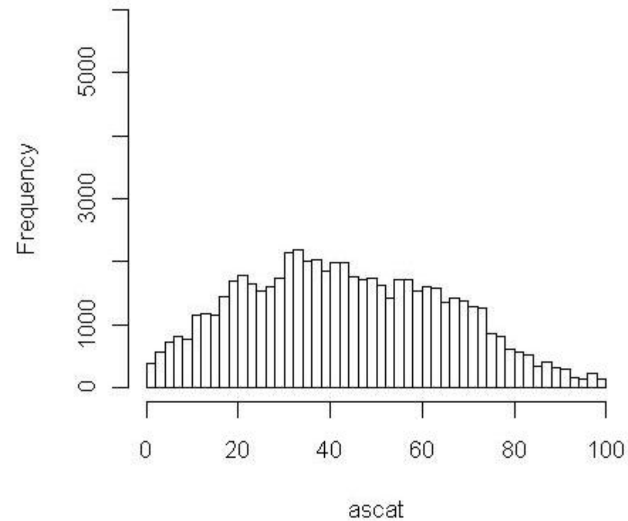
Statistical Downscaling

Calibration (bias correction) with CDF matching

Cumulative distribution function matching (Reichle & Koster, 2004)







4th order polynomial fit: Expectation, Variance, Skewness, Kurtosis

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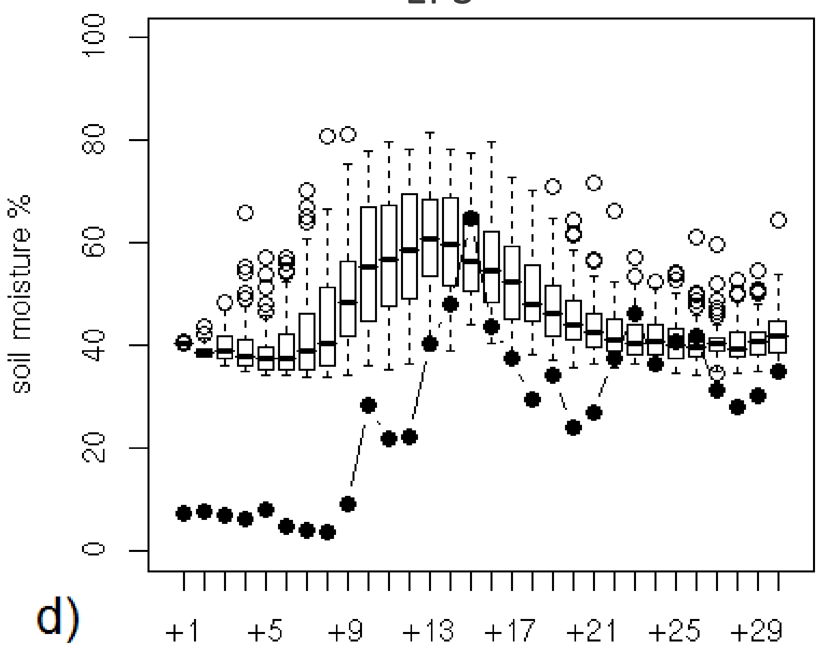
Statistical Downscaling

Calibration

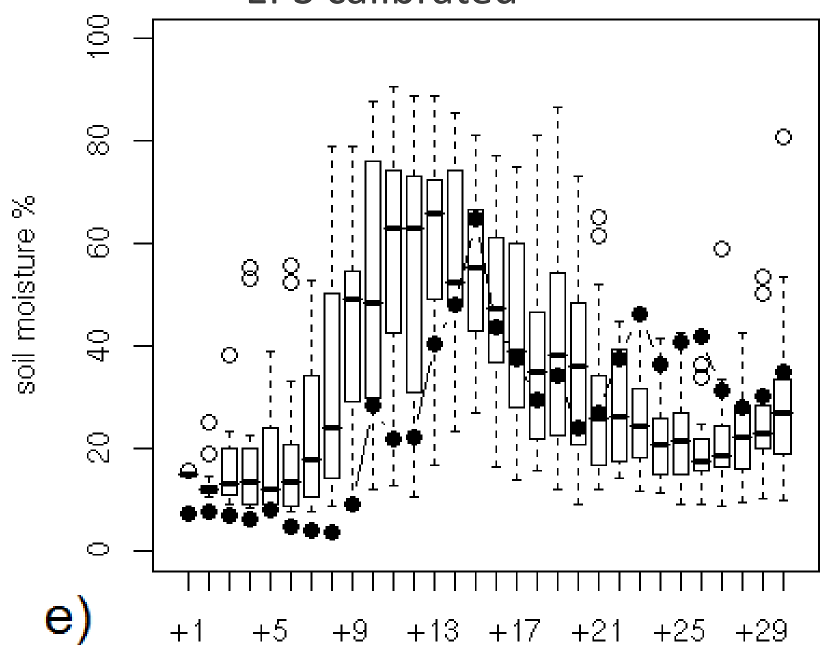
<u>Cumulative distribution function (CDF) matching</u>

for each model grid point separately
-> EPS histogram matching to ASCAT histogram

EPS



EPS calibrated

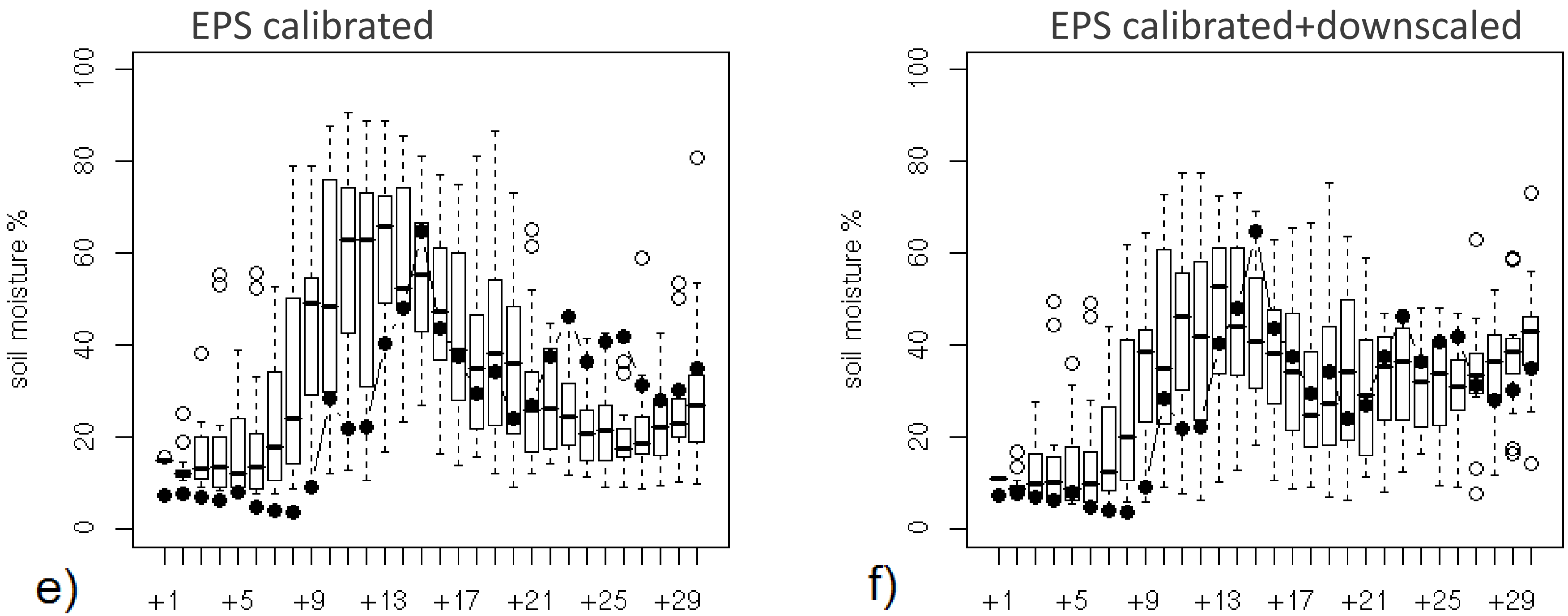


Statistical Downscaling

Calibration

METOP-A ASCAT – ENVISAT ASAR relationship

applying linear relationship to calibrated EPS data
-> EPS on 1km grid



Geodynamik

Statistical Downscaling

Result

Statistical downscaling of **seasonal forecasts** by the use of satellite soil moisture could be used to **support** localized long-term **decision making**, e.g. for choosing the ideal seed

Details of the downscaling approach:

Schneider et al., 2014: Calibration and downscaling of seasonal soil moisture forecasts using satellite data. HESS, 18, 2899–2905, doi:10.5194/hess-18-2899-20

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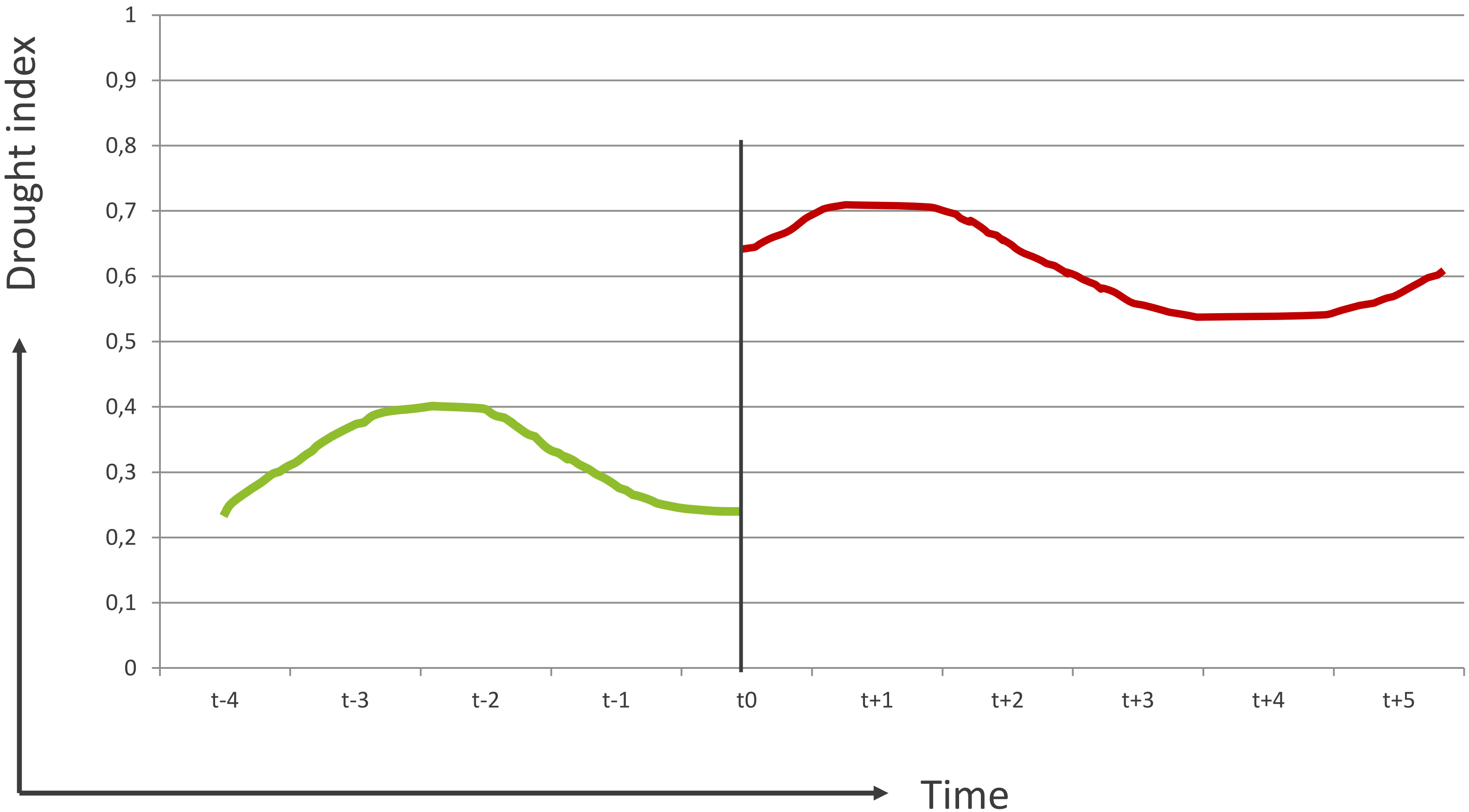
Common timeseries

Basic idea:

Combine satellite-based ECDI with forecasted ECDI from a seasonal ensemble prediction system (ECMWF System 4)



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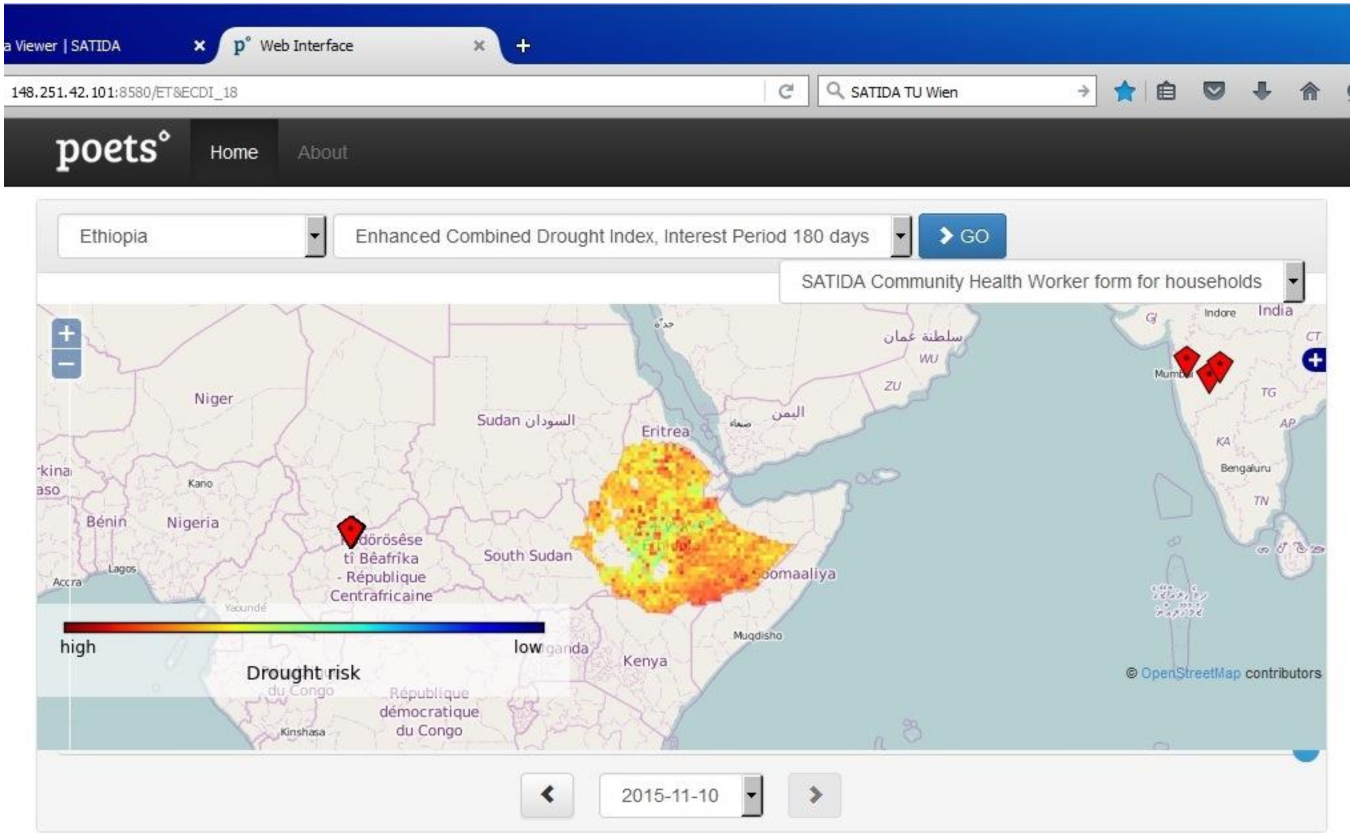
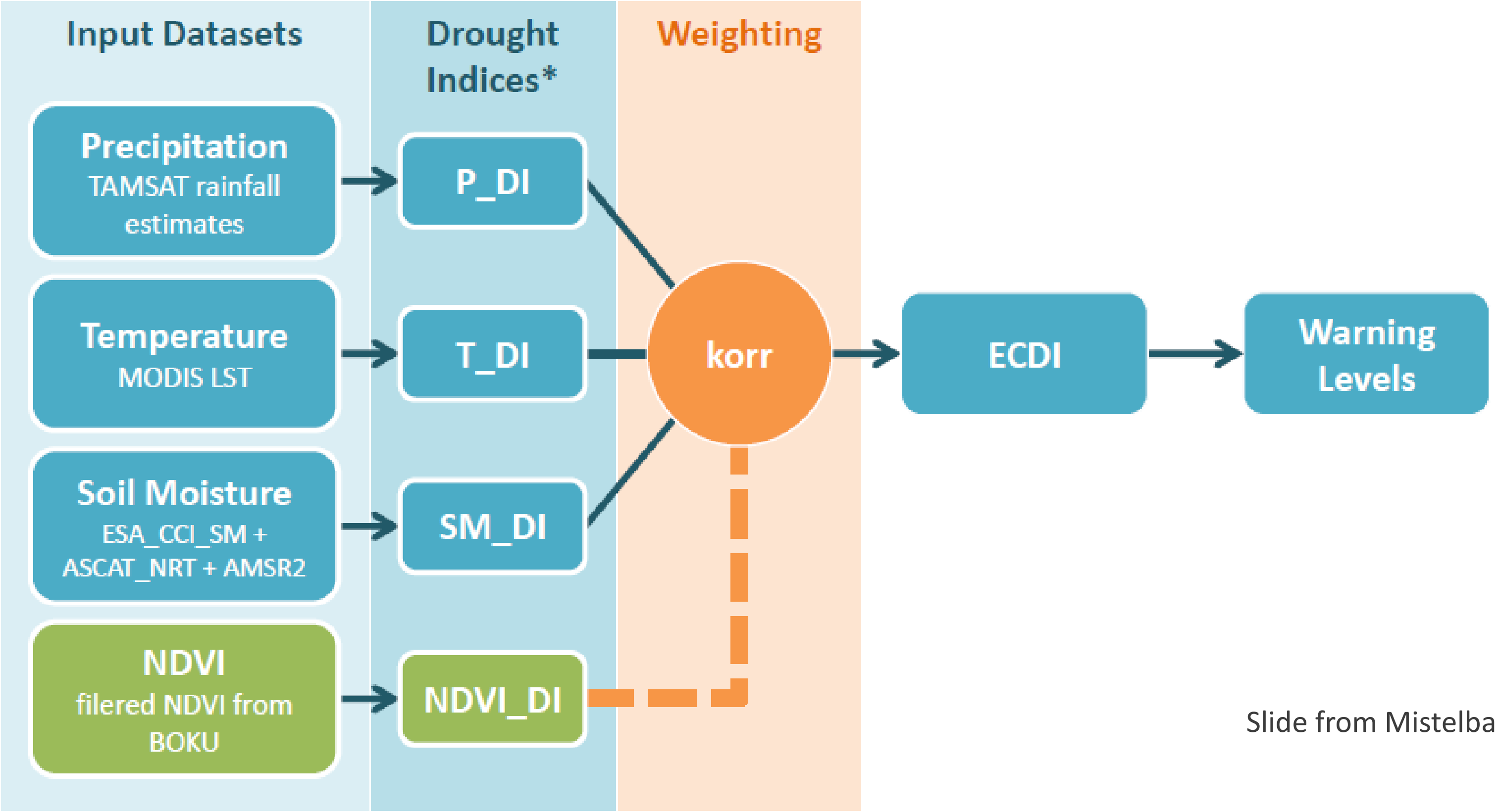
Enhanced Combined Drought Index – ECDI

Combine different satellite data sources to produce one stable drought monitoring index (http://satida.net/)



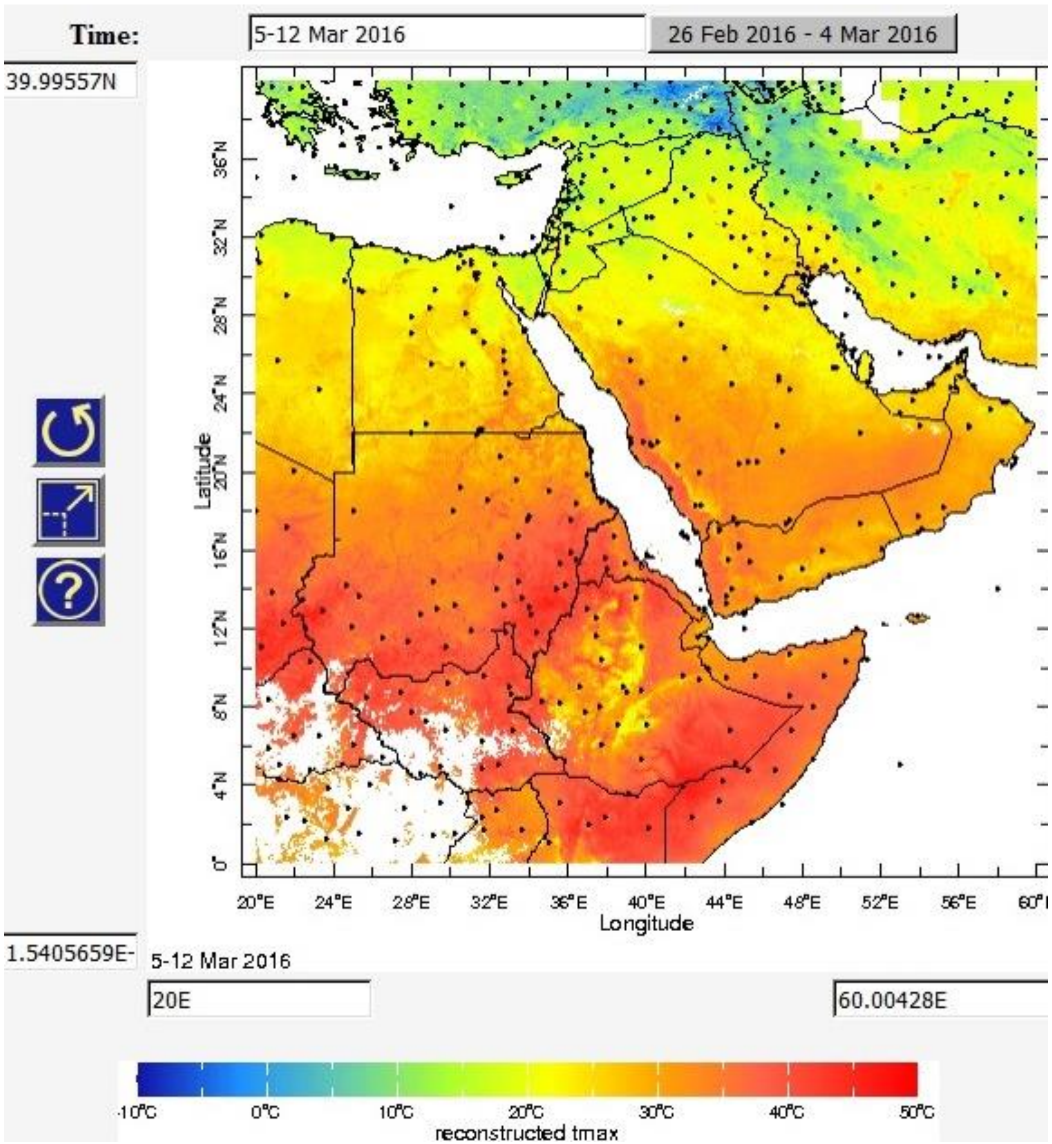
Enhanced Combined Drought Index (ECDI)



Slide from Mistelbauer and Enenkel

*http://www.faoswalim.org/downloads/Combined Drought Index.pdf

Drought monitoring & forecasting



MODIS

(Moderate Resolution Imaging Spectroradioneter)

Land surface temperature

http://iridl.ldeo.columbia.edu/maproom

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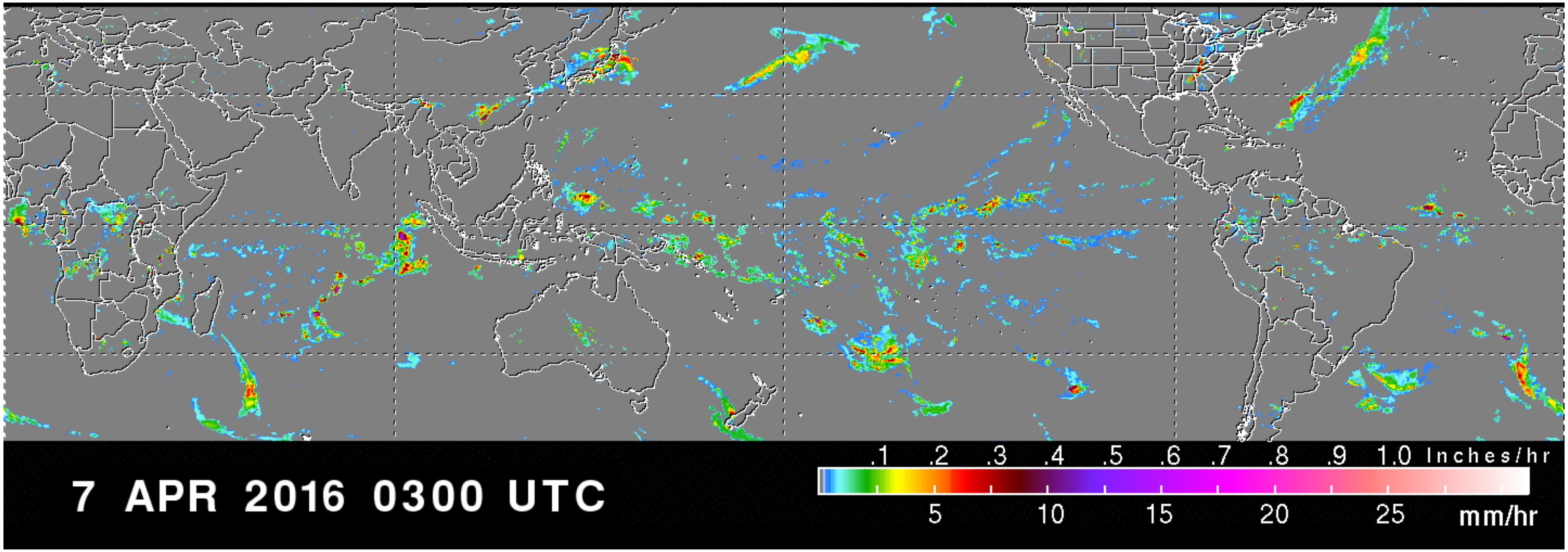
TRMM

(Tropical Rainfall Measuring Mission)

Precipitation



http://trmm.gsfc.nasa.gov/trmm_rain

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Drought monitoring & forecasting

Basic idea:

Combine satellite-based ECDI with forecasted ECDI from a seasonal ensemble prediction system (ECMWF System 4)

Satellite	Model ECMWF Seasonal EPS 4
MODIS Surface temperature	T2M, 6 hourly
TRMM precipitation	Precipitation, 24hourly sum
ECV surface soil moisture	Soil moisture content 0-7cm, 24 hourly

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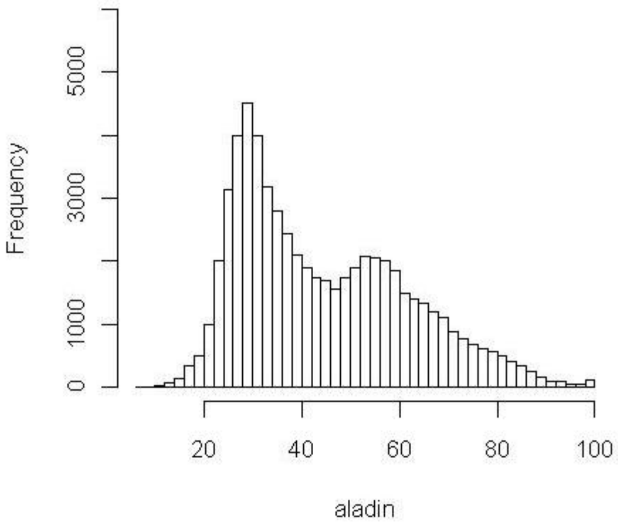
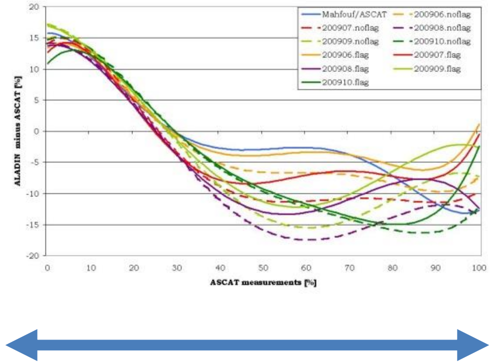
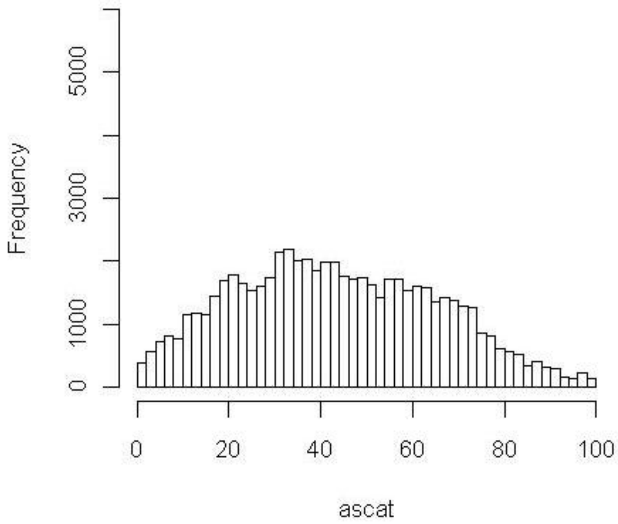
CDF matching

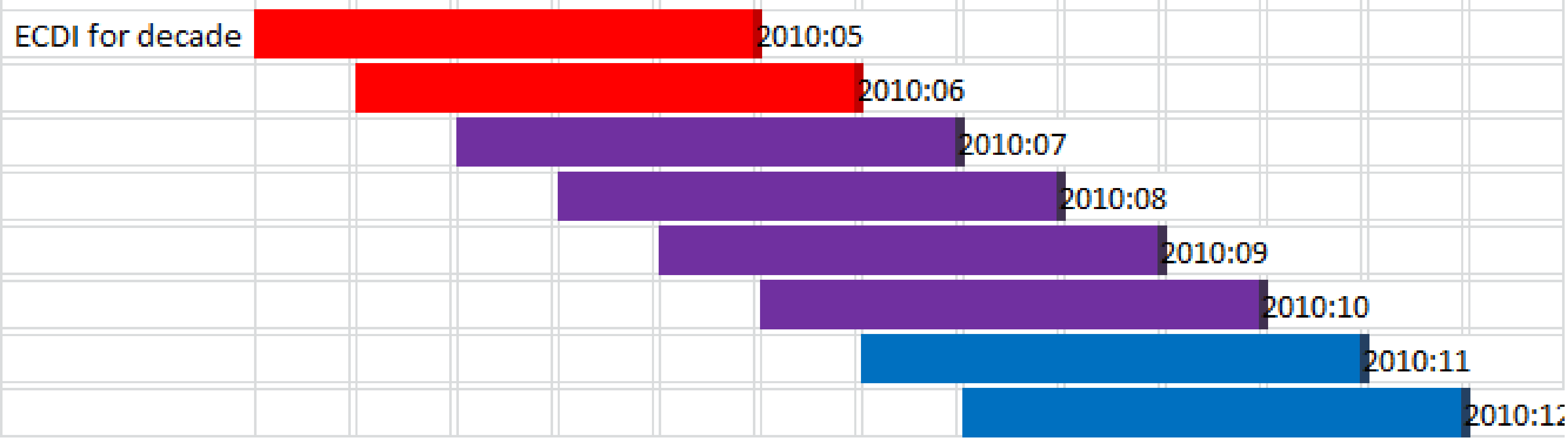




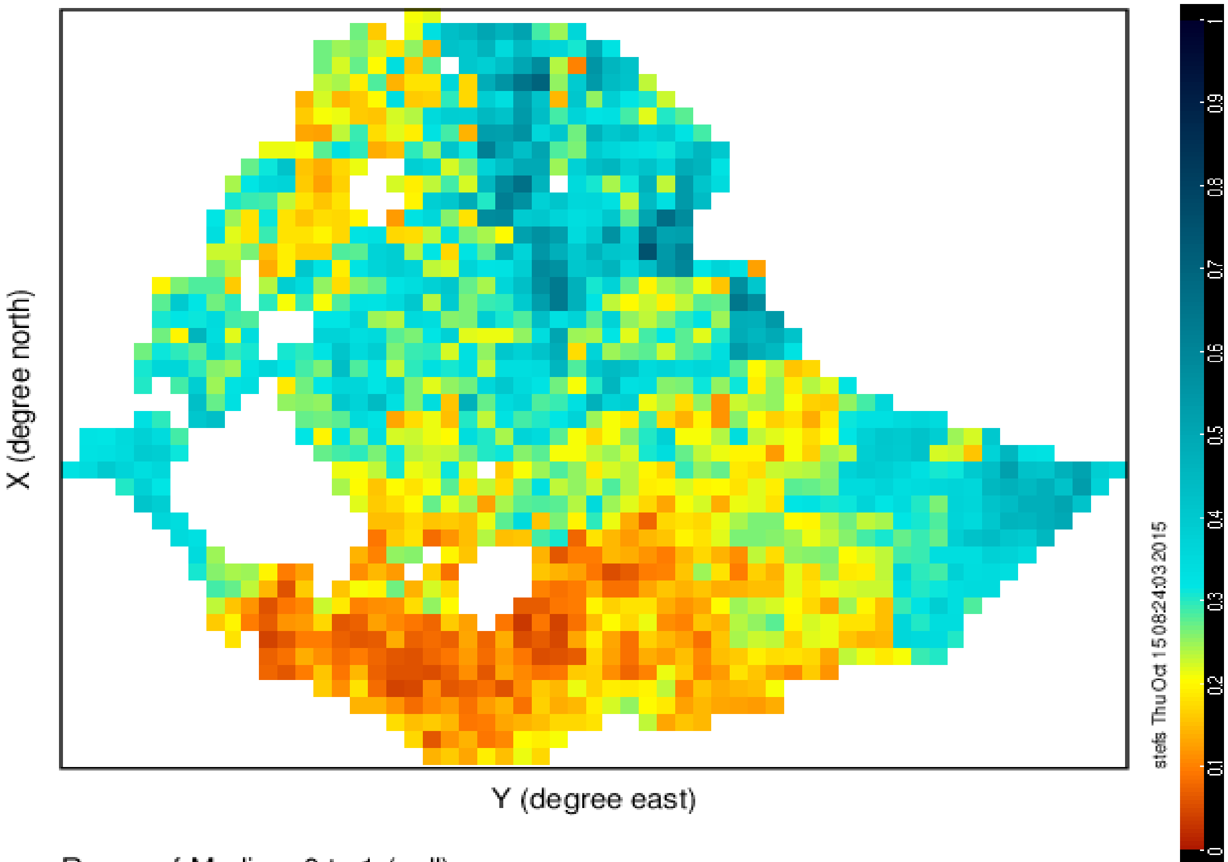


Drought monitoring & forecasting

date	2010-01-10	2010-01-20	2010-01-31	2010-02-10	2010-02-20	2010-02-28	2010-03-10	2010-03-20	2010-03-31	2010-04-10	2010-04-20	2010-04-30
data source	Sat	Sat	Sat	Sat	Sat	Sat	Mod	Mod	Mod	Mod	Mod	Mod



Drought monitoring & forecasting



Range of Median: 0 to 1 (null)
Range of Y: 33.125 to 47.625 degree east
Range of X: 3.625 to 14.625 degree north
Current time: 14 decades since20080201 00:00:00

- Use forecasted ECDI just for decades +1 and +2 (20 days is much more than weather forecast can provide !), afterwards climatology is the better choice.
- Do not use single grid point values for decision making.
- Information on model uncertainty is a benefit.

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Result

Combined **drought monitoring** and **forecasting** can support aid organisations in **detecting** hot spots **where help is** (and will be) **needed** most.

Details of the ECDI approach:

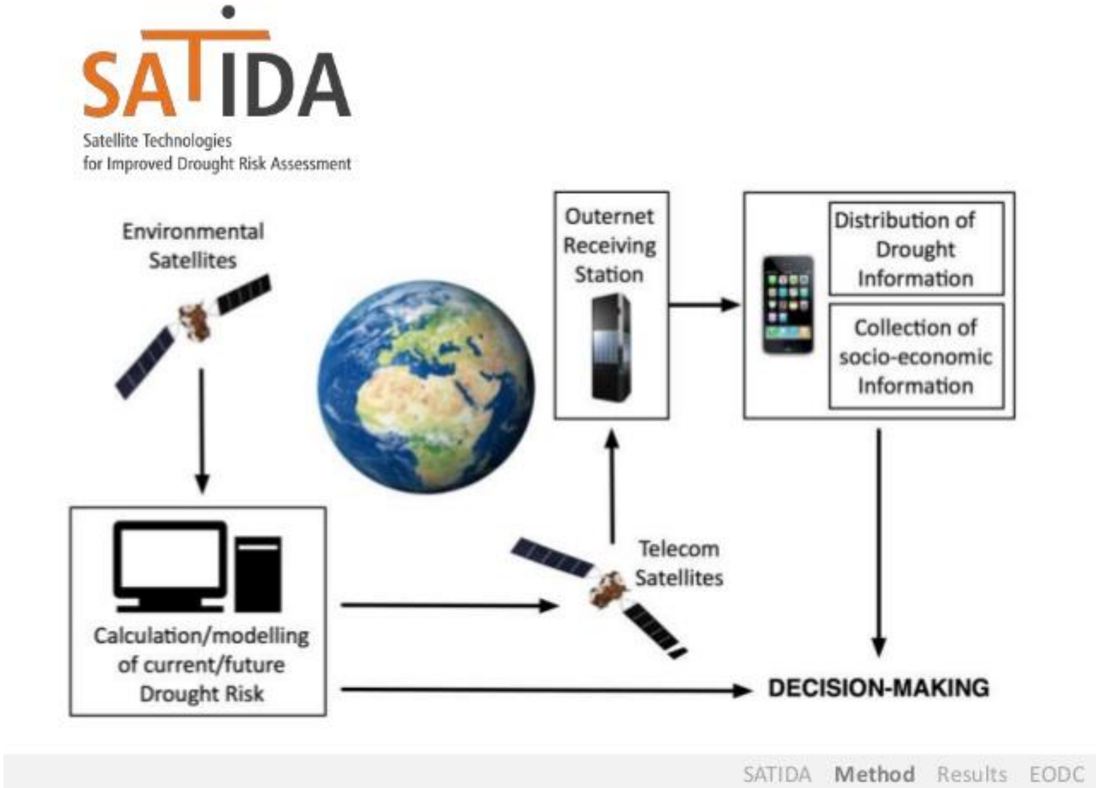
Enenkel et al., 2016: A combined satellite-derived Drought Indicator to support Humanitarian Aid Organizations. Remote Sensing, accepted

Overview

- How to measure soil moisture by satellites
- Combining measurements and model data
- Drought monitoring & forecasting
- Conclusions & outlook

outlook

- New satellites like ESAs Sentinel satellites will provide extreme amounts of new data (several TB of raw data per day)
- Big Data approaches needed
- How to bring the information to the user? - Apps



Conclusions

3 things to take back home from this presentation

- ✓ Satellite soil moisture is a powerful data source
- ✓ Combine different data sources
- ✓ Developed new applications

Thanks for your attention!

Questions?

ask now or write to

stefan.schneider@zamg.ac.at

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