Assimilation of SMOS Data: Plans and Expected Results

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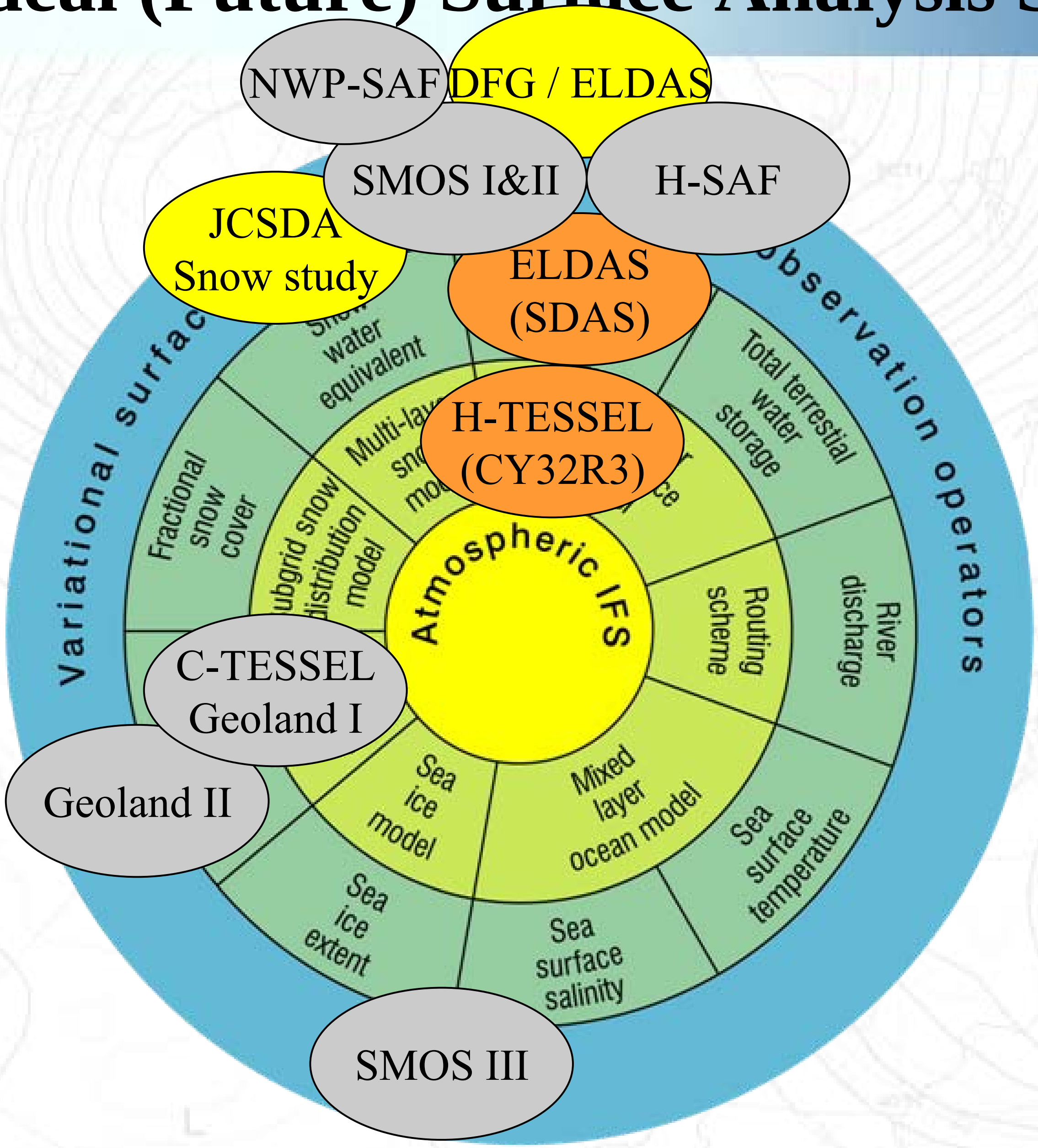
An Ideal (Future) Surface Analysis System

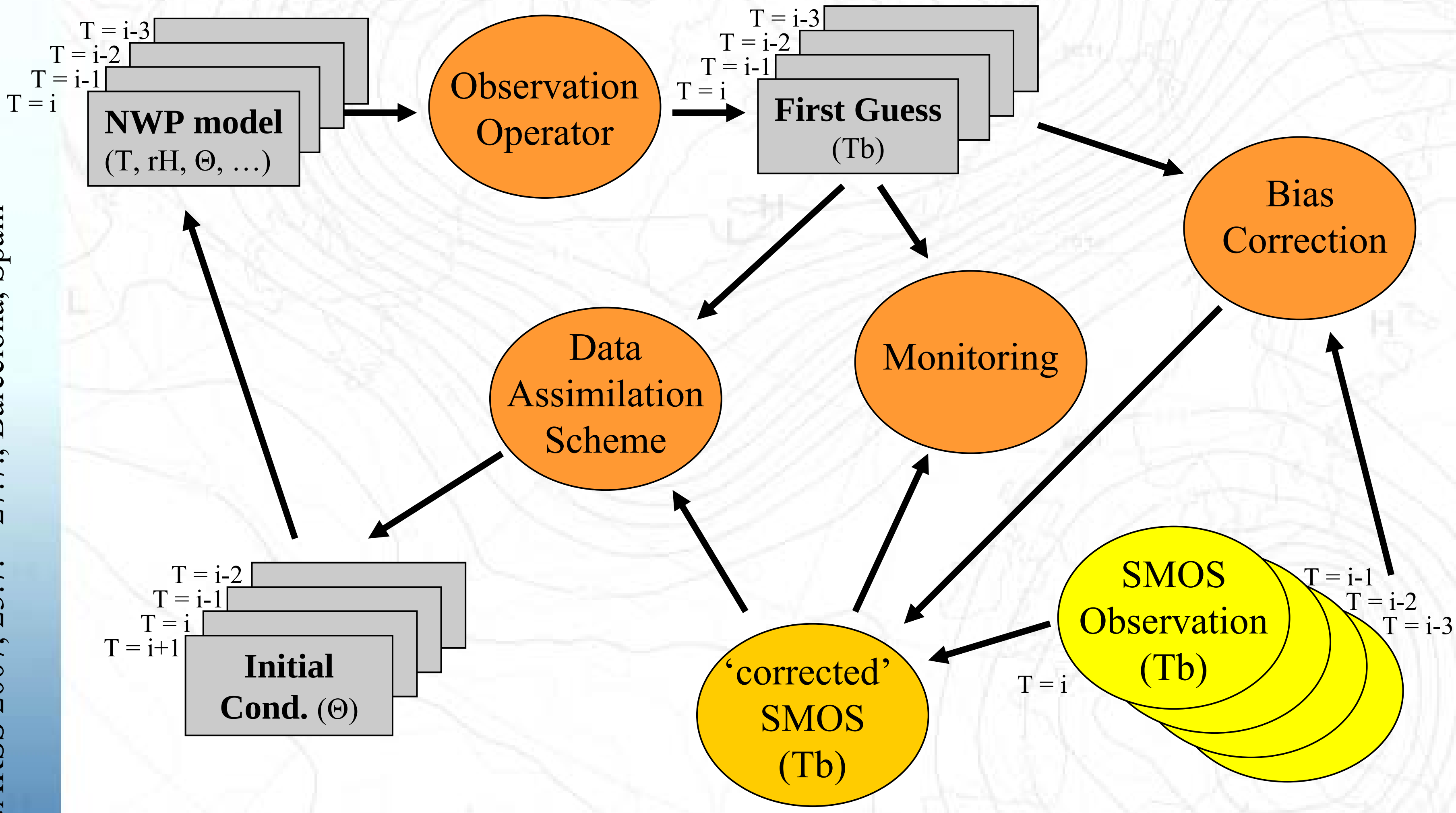


‘Soil Moisture and Ocean Salinity (SMOS) Data Assimilation Study’ (NC114)

- Kick – off: January 2007
- ESA-funded project work starts: 1st August 2007
- Duration of Phase I: 27 months
- Possible extensions (Phase II & III) envisaged
- Key objectives Phase I:

1. Implementation of a global L-band emissivity model.
2. Global monitoring of TOA brightness temperatures and surface soil moisture.
3. Further development of the variational surface data assimilation system.
4. Data assimilation impact studies using ECMWF’s operational Integrated Forecast System and SMOS brightness temperatures over land.

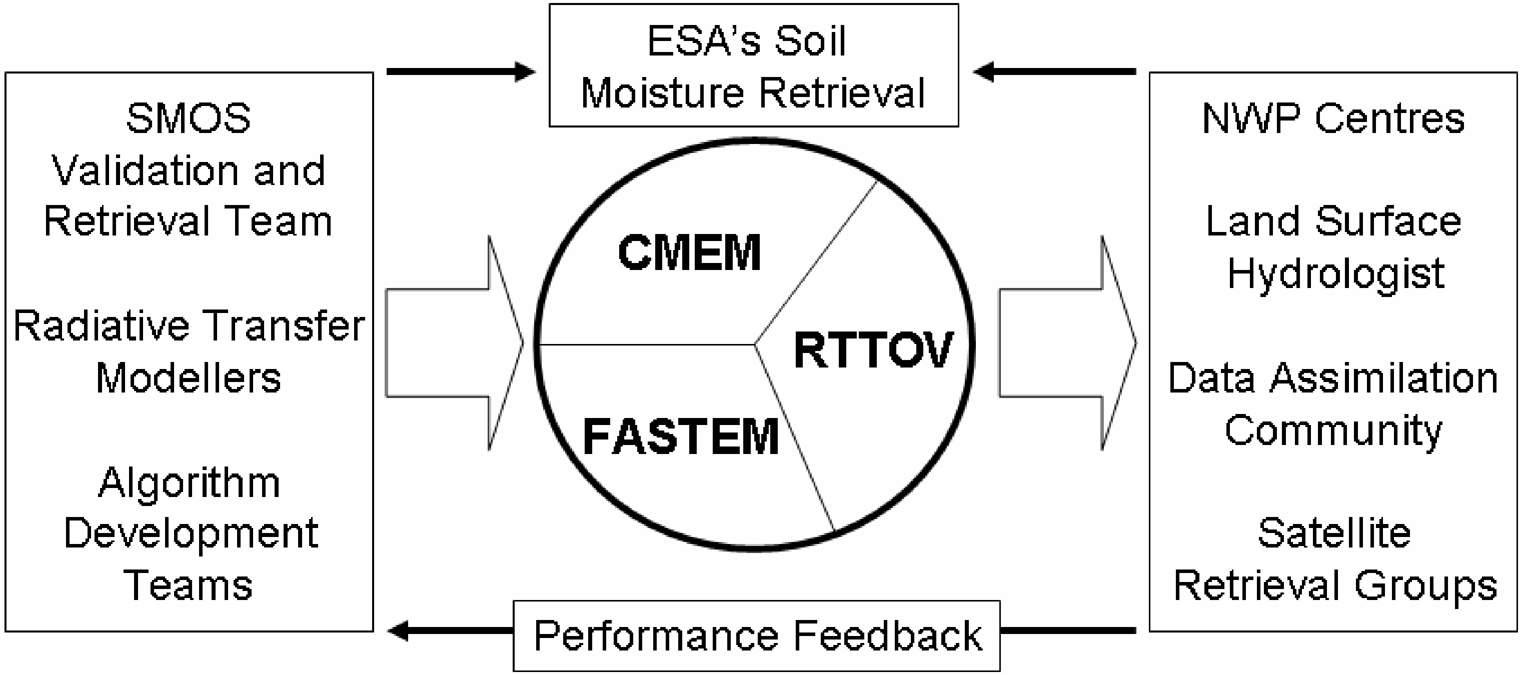
A Schematic View on Data Assimilation



IGARSS 2007, 23.7. – 27.7., Barcelona, Spain

Observation Operator
Community Microwave Emission Model

- **In general, NWP Centres do not have the man power to develop radiative transfer models.**
- **However, near-real time applications often require the assimilation of brightness temperatures or radiances (rather than derived parameters).**
- **There is a need for 'community models', which are well documented and maintained. The infrastructure is in place: NWP-SAF at the UK Met Office.**



Observation Operator
Community Microwave Emission Model

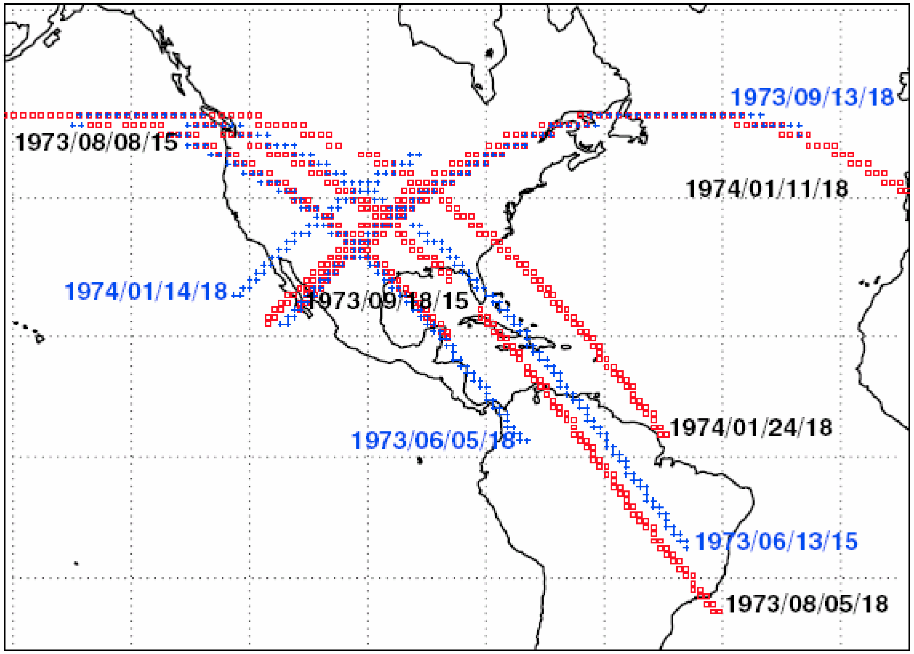
TABLE II
DEFAULT MODEL CONFIGURATION FOR L-BAND AND OPTIONAL MODULES. ALL MODULES ARE DESCRIBED IN SECTION II. VEGETATION PARAMETERS INCLUDE VALUES FOR LOW AND HIGH VEGETATION.

Components	*Default Module*	*Optional Modules*		
T_{eff}	Wigneron [22]	Holmes [23]	Choudhury [21]	
ϵ_{soil}	Dobson [25]	Wang-Schmugge [24]		
r_s	Fresnel law	Wilheit [18]		
r_r	Wigneron I [22]	Wegmüller [32]	Wigneron II [22]	Choudhury [30]
vegetation	Kirdyashev [33]	Wigneron [47]	Wegmüller [32]	
snow	Pulliainen [36]			
atmosphere	Pellarin [48]	Liebe [39]		

Parameters	*Default*	*L-MEB Setup*	*LSMEM Setup*
$sal_{soil}[psu]$	0	0	0.65
$sal_{veg}[psu]$	6	6	6
$sal_{sea}[psu]$	32.5	32.5	–
r_r- module	Wigneron I [22]	Wigneron II [22]	Wegmüller [32]
L_c/s or $\sigma[cm]$	$L_c/s = 6.0/2.2$	$L_c/s = 6.0/0.15$	$\sigma = 0.5$
$Q[-]$	0	0	$f(\sigma)$
Nrp	0	0	2
$VWC[kgm^{-2}]$ (L,H)	$f(vegtype)$	$f(vegtype)$	$(1.0, 4.0)$
$\omega[-]$ (L,H)	$(0.05, 0.05)$	$(0.\ to\ 0.05, 0.15)$	$(0.05, 0.05)$
vegetation module	Kirdyashev [33]	Wigneron [47]	Wegmüller [32]
a_{geo} or $b[m^2kg^{-1}]$ (L,H)	$a_{geo} = (0.33, 0.66)$	$b = (0.2, 0.33)$	$b = (0.33, 0.33)$

Calibrating CMEM Using ERA-40 and SKYLAB: The Mission

Is it possible to calibrate CMEM to obtain bias free TBs on the continental scale?
Are there any systematic differences between the obs. and the fg?
What is the inter-annual / seasonal variability of TB?



SKYLAB facts:

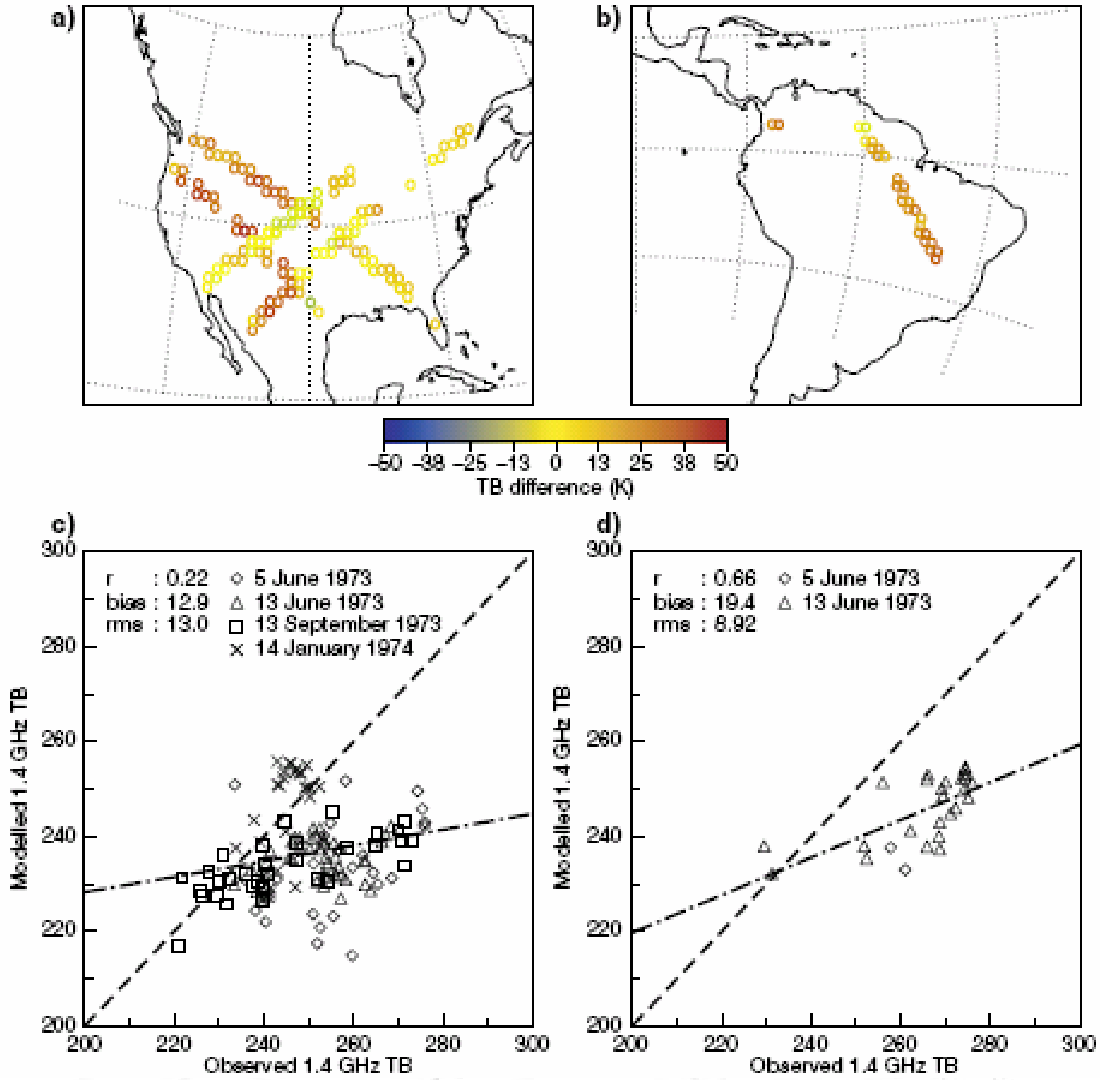
- launch 14 May 1973
- nominal altitude 435 km
- back on earth 11 July 1977
- data collection required astronaut

S-194 facts:

- L-band radiometer
- nadir looking
- 110 km resolution
- 2.5 km sampling
- most measurements were lost, 9 overpasses could be recovered from print-outs …

Observation Operator – CMEM:

Calibrating CMEM Using ERA-40 and SKYLAB



Data:

- S-194 L-band TB

- ECOCLIMAP LAI
- (C-TESSEL)
- ERA soil moisture
- ERA soil temperature
- ERA 2 m temperature
- ERA snow depth
- FAO soil types
- (H-TESSEL)

Calibrating:

- surface roughness,
- vegetation structure coef.
- single scattering albedo

First Guess

Calibrating CMEM Using ERA-40 and SKYLAB

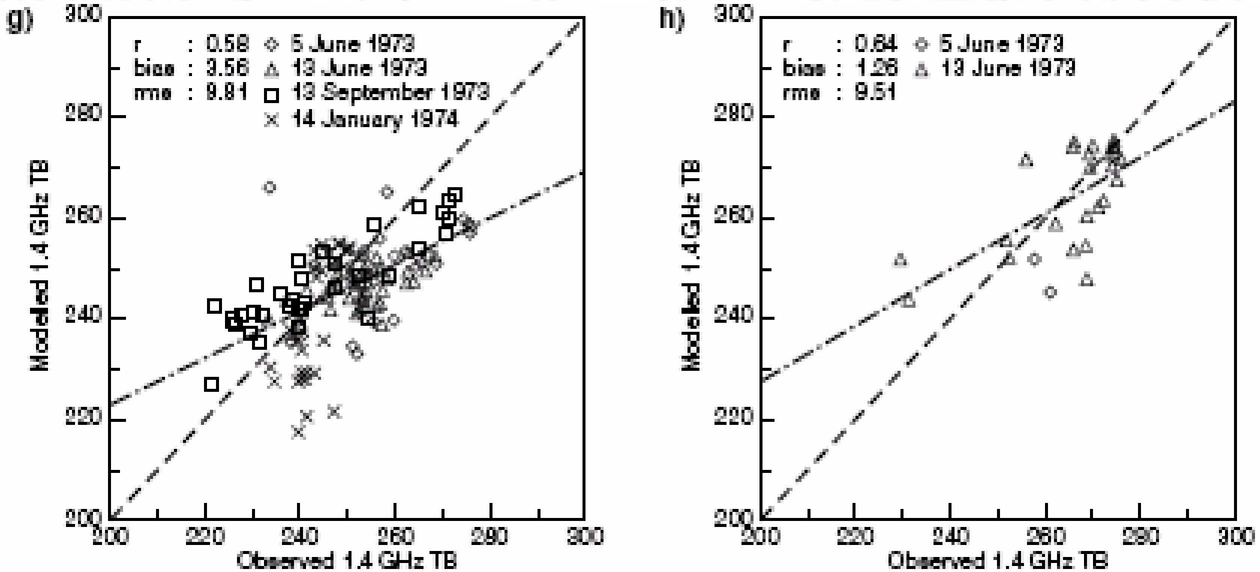
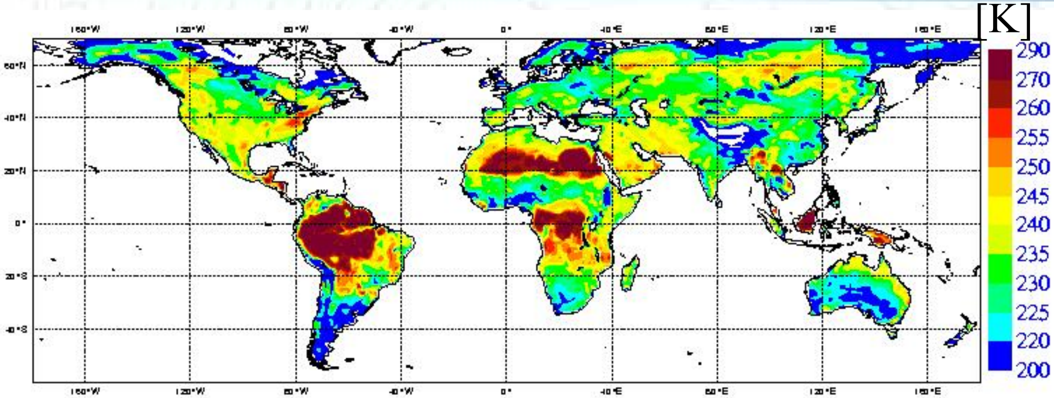


Table 1: CMEM model setup for the calibration and validation computations.

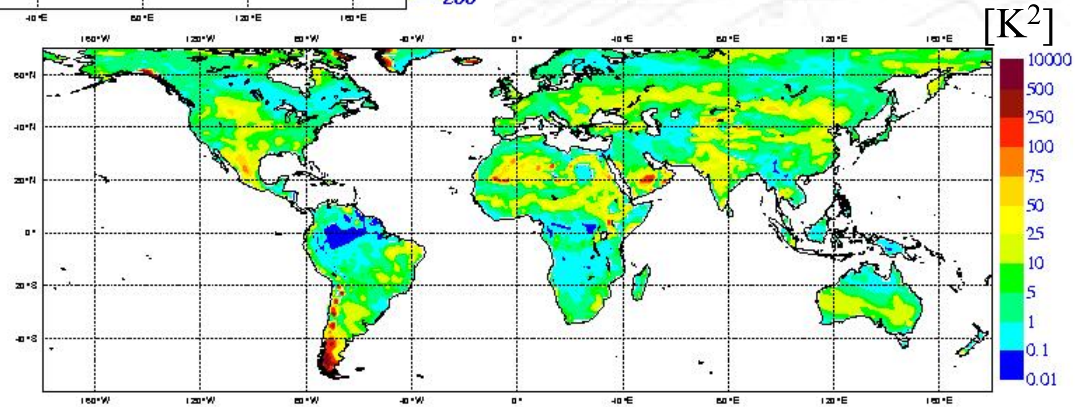
SetUp	Roughness	Vegetation	σ	$\omega(L,H)$	b (L,H)	$a_{geo}(L,H)$	$VWC_{trop.}$
A	Wigneron (Eq.4)	Wigneron	0.15	(0.05, 0.15)	(0.2, 0.33)		6
B	Wigneron (Eq.4)	Wigneron	2.2	(0.05, 0.05)	(0.2, 0.33)		6
C	Wigneron (Eq.5)	Wigneron	2.2	(0.05, 0.05)	(0.2, 0.33)		6
D	Wigneron (Eq.5)	Kirdyashev	2.2	(0.05, 0.05)		(0.33, 0.33)	6
E	Wigneron (Eq.5)	Kirdyashev	2.2	(0.05, 0.05)		(0.33, 0.66)	10

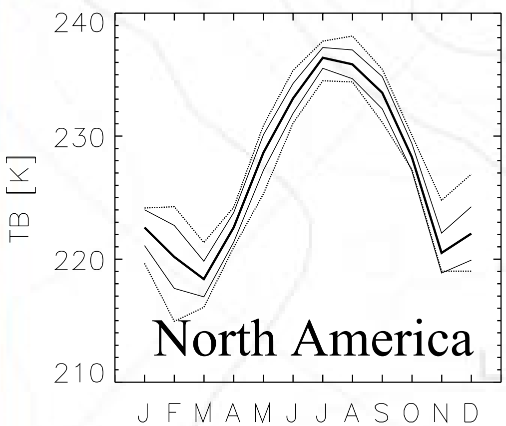
Observation Operator – CMEM:
ERA-40-based Climatology

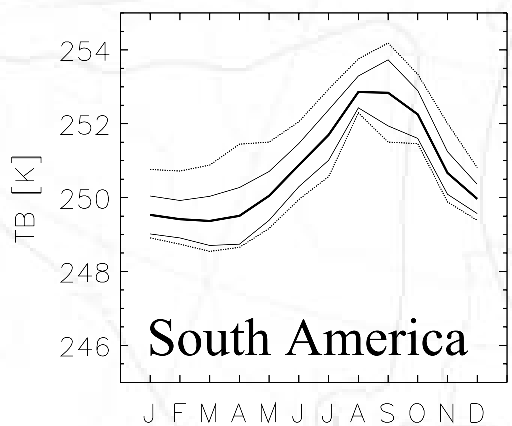


July 1990 – 2000: mean

July 1990 – 2000: variance







mean annual cycle in TOA TB for 1991 to 2000

Summary Part I

- Calibrating a forward model or a retrieval algorithm is an ill-posed problem: Many parameters are unknown on the global scale, each auxiliary data set has (undefined) systematic and random errors.
- It is possible to get a ‘bias-free’ first guess using a constant value for surface roughness.
- Systematic differences remain, i.e. the modelled dynamical range is too small. => An additional ‘bias-correction’ scheme is needed!
- Apart from soil moisture, vegetation is THE critical parameter … ECMWF’s static vegetation data base is probably not good enough.
- The rms in TOA TB can be explained by uncertainties in soil moisture (comparison against in-situ data, not shown).
- The variability on the continental scale is comparably small. Only few SMOS observations may be needed to evaluate the initial set up.

Implementation plan at ECMWF:

- Global data monitoring will start with a fixed roughness parameter and the ECOCLIMAP data base.
- CMEM will be updated and re-calibrated after the commissioning phase.
- DA can potentially start 8-12 months after launch.

Impact Study Using TMI-derived Soil Moisture Over the Southern U.S.

Motivation:

- Systematic model errors deteriorate soil moisture and consequently the forecast quality.
- The proxy 'observations' are efficient in improving the turbulent surface fluxes and consequently the weather forecast on large geographical domains. However, the current analysis fails to produce more accurate soil moisture estimates.
- Can satellite-derived soil moisture improve the analysis without deteriorating the forecast?

NWP Experiments:

1. **Open Loop**, no soil moisture analysis.
2. **Optimal Interpolation** using 2m temperature and relative humidity analyses.
3. **Nudging** using TMI derived surface soil moisture.

- atmospheric 4-DVar (including ~ 6 Mio. Satellite observations per day)
- T511 spectral resolution (~ 35 km)
- June and July 2002

TMI Pathfinder Data Set

Data set produced by:

Dept. Civil and Environmental Engineering, Princeton University, NJ

Basis:

brightness temperatures at 10.65 GHz horizontal polarization

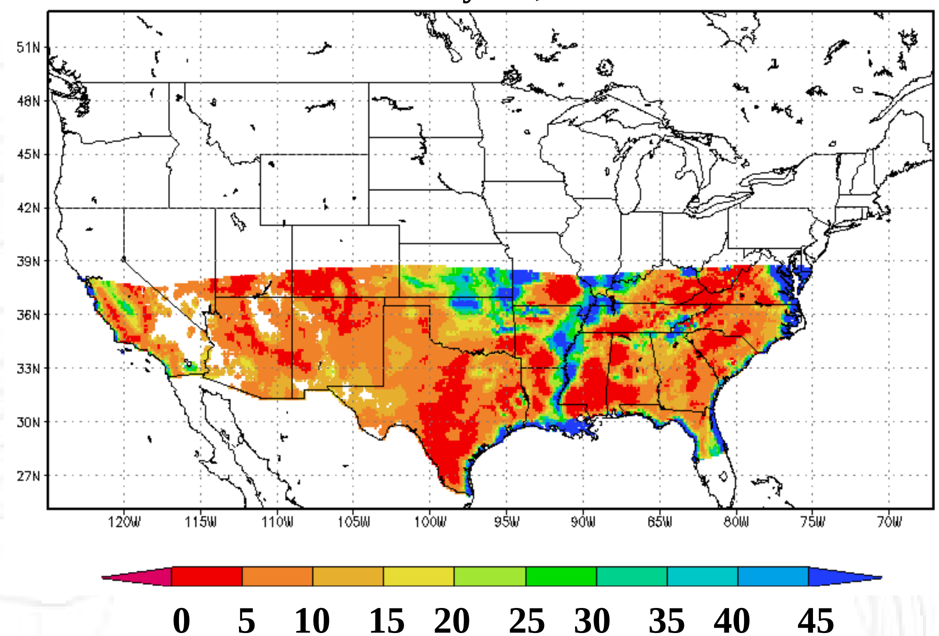
Method:

physical retrieval based on land surface microwave emission model and auxiliary data sets from the North American Land Data Assimilation Study project

Output:

surface soil moisture [cm^3 cm^{-3}],

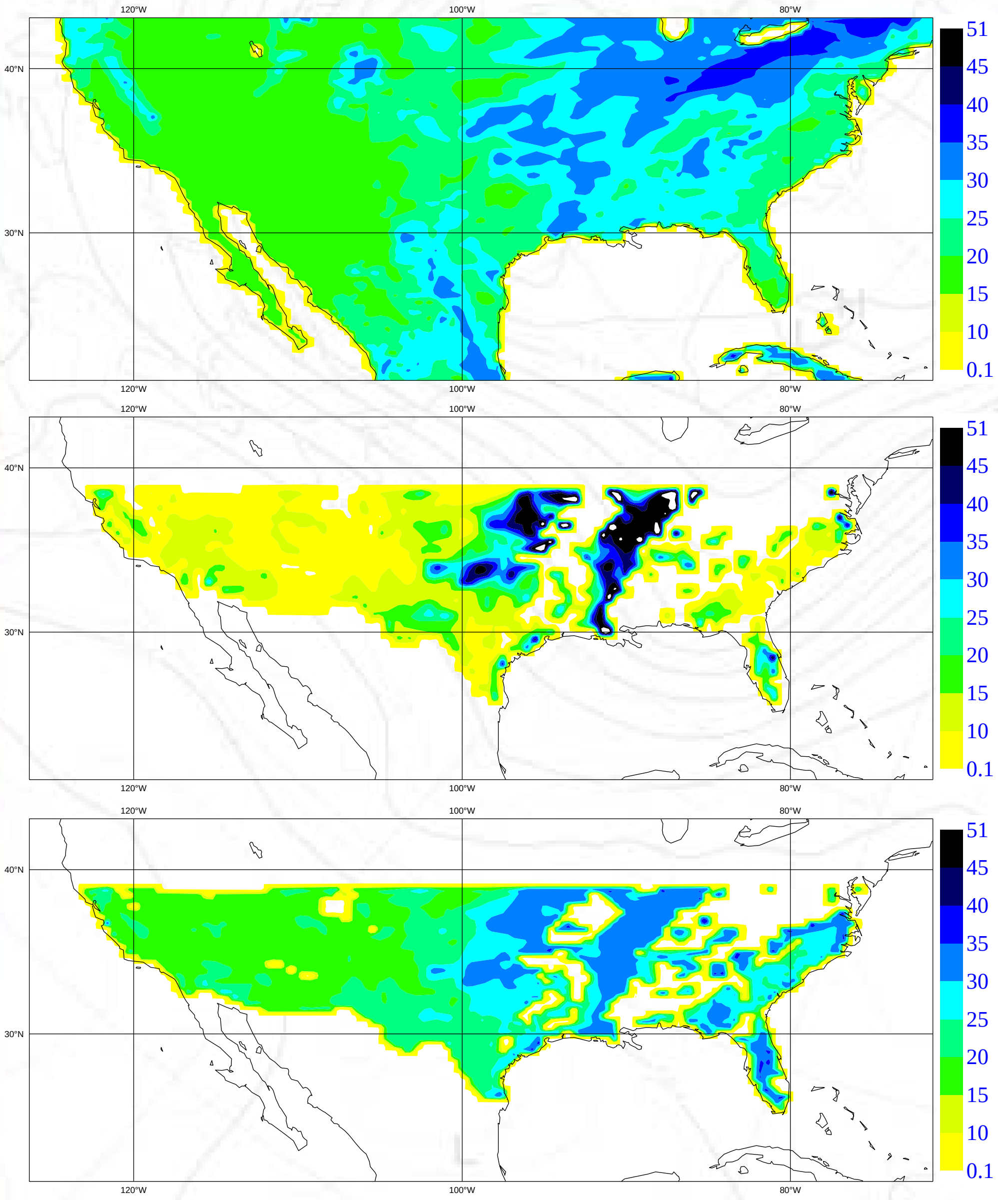
July 2nd, 1999



(%) (Gao et al. 2006)

Bias-corrected TMI Soil Moisture

volumetric surface soil moisture [%] for 06/06/2002

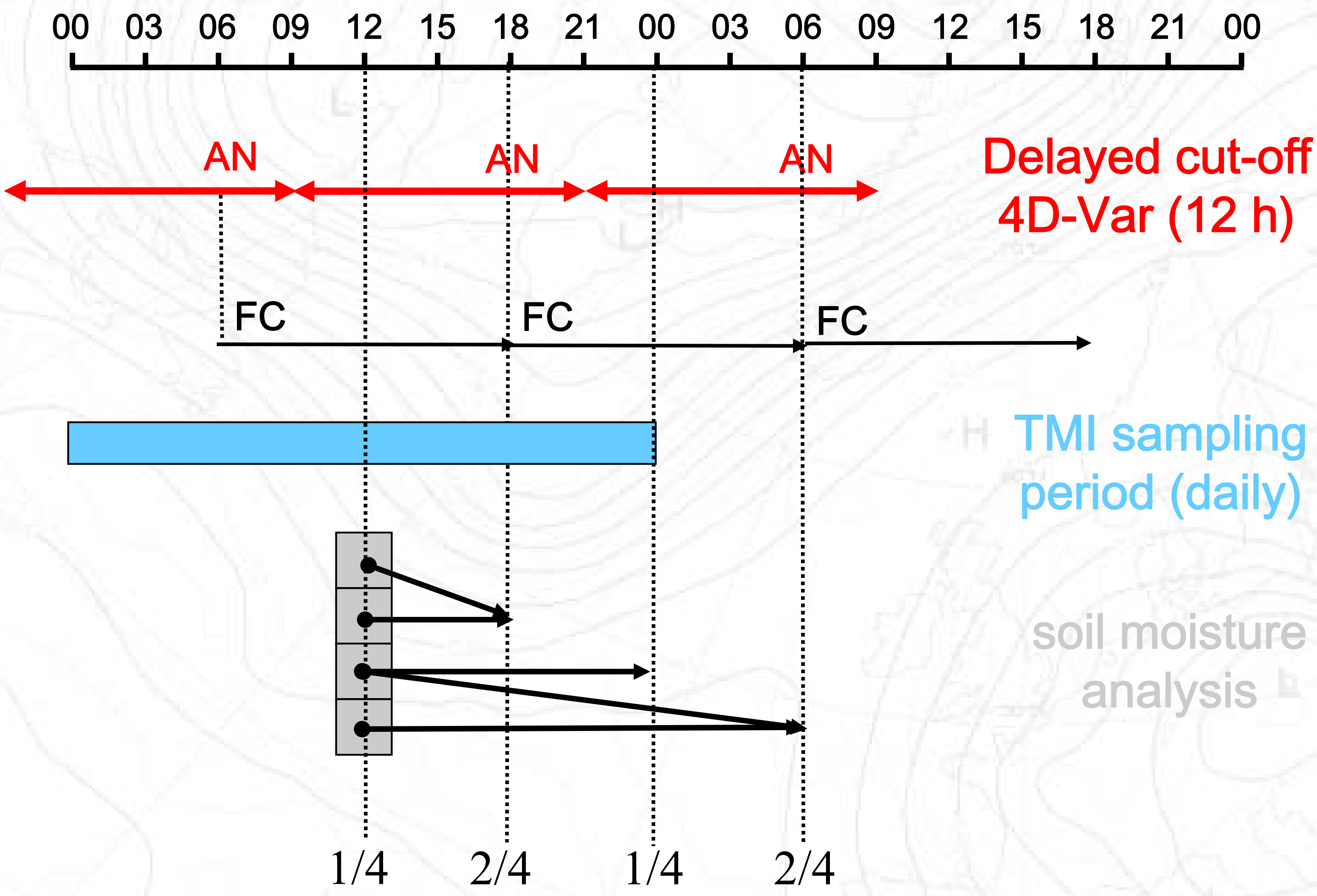


the modelled first guess

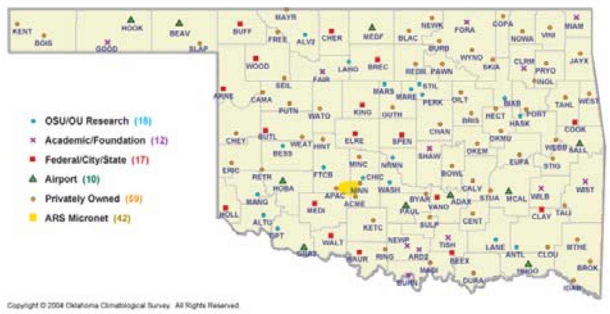
TMI Pathfinder data

bias-corrected TMI data set (CDF-matching)

Nudging set up

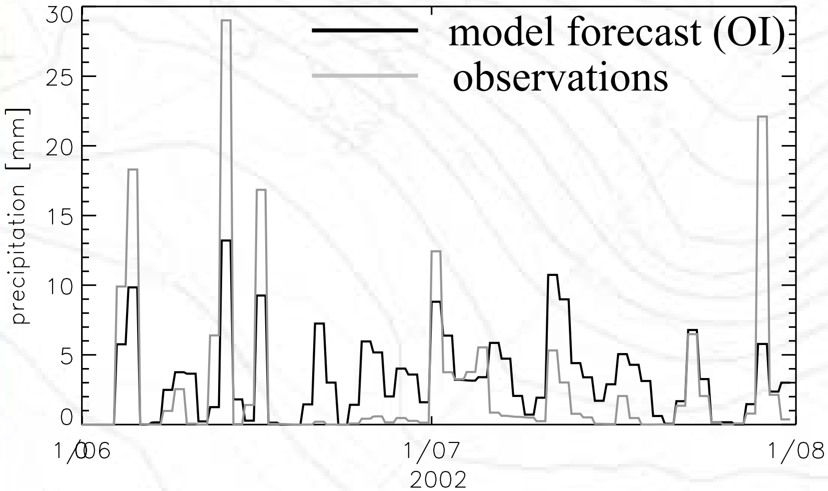


Validation of Forcing Data

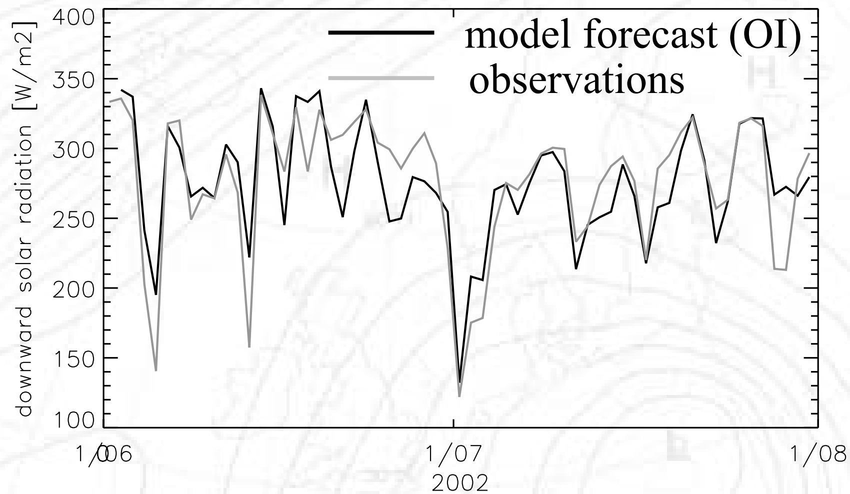


area averages for Oklahoma
(72 stations, equally distributed)

daily precipitation



daily downward shortwave radiation



total amount of rainfall:

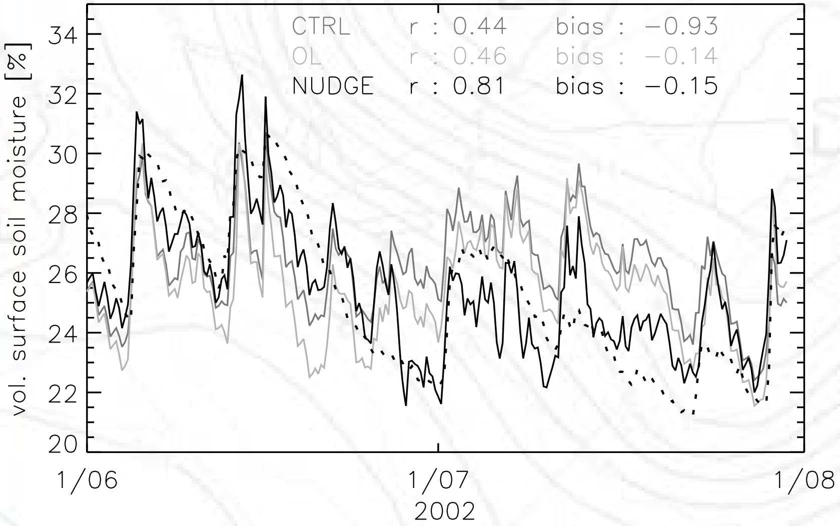
June	87.3 mm model	on	19 days
	87.8 mm observations	on	9 days
July	110. mm model	on	26 days
	79. mm observations	on	20 days

Correlation : 0.85
Bias : - 0.7 Wm^{-2}

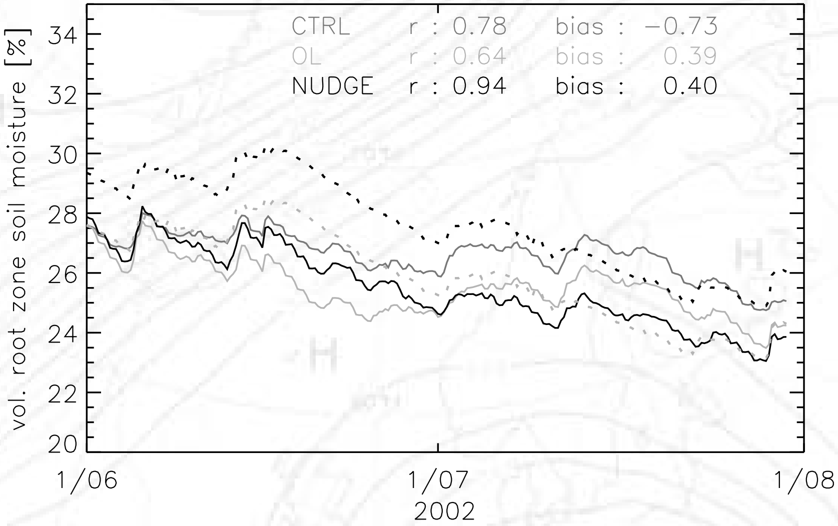
Validation of soil moisture

area averages for Oklahoma

surface soil moisture



root zone soil moisture



- Nudging / satellite data remove water effectively and produce a realistic dry down.
- Nudging the satellite results in the most accurate surface soil moisture estimate.

- The information introduced at the surface propagates to the root zone.
- The monthly trend is well reproduced using the nudging scheme.

Satellite derived soil moisture improves the soil moisture analysis and results in the most accurate estimate.

Impact on weather parameters

CTRL | Open Loop | NUDGE

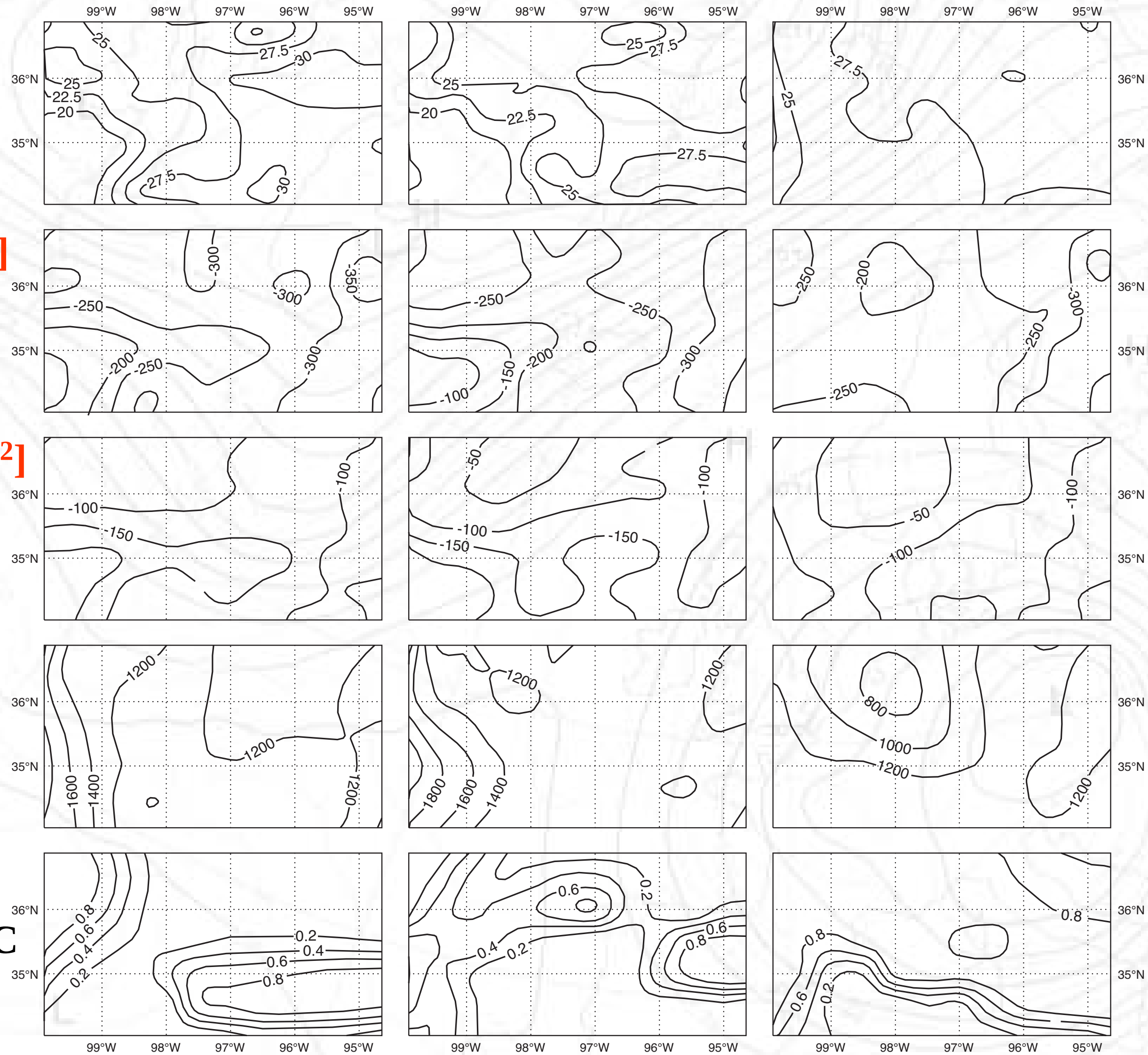
surface soil moisture [%] at 18 June, 12 UTC

latent heat flux [Wm^{-2}] mean over 18 June 12 UTC to 00 UTC

sensible heat flux [Wm^{-2}] mean over 18 June 12 UTC to 00 UTC

planetary boundary layer height [m] at 19 June 00 UTC

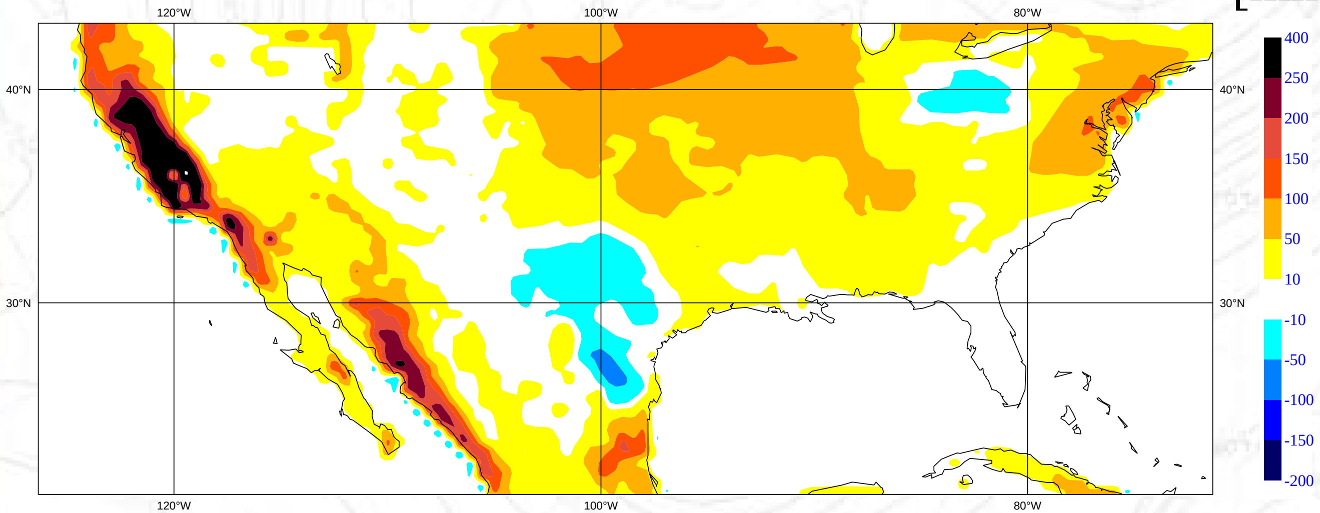
total cloud coverage [0-1] at 19 June 00 UTC



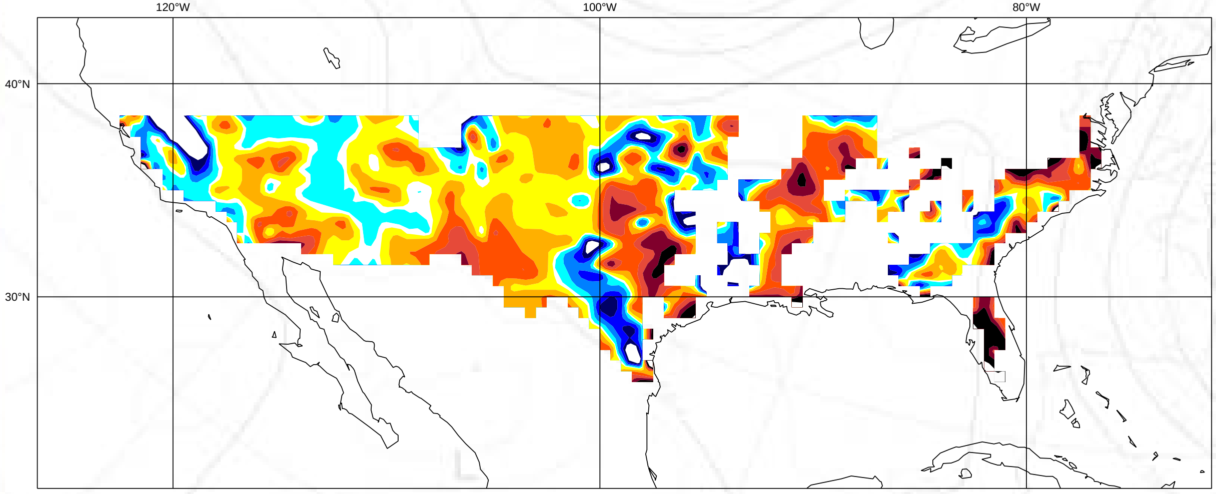
Soil moisture increments

accumulated increments over June and July 2002

[mm]



Optimal Interpolation (2 m T and RH)



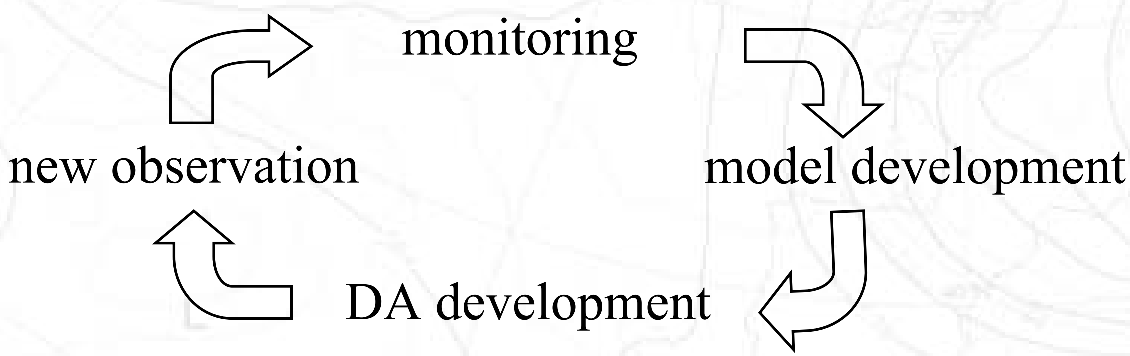
Nudging (TMI soil moisture)

Summary

Soil moisture influences the atmosphere including some of the most important parameters, i.e. 2 m temperature, relative humidity and precipitation, and has and impact on the forecast skill. The current analysis improves the fluxes and the short-range forecast but fails to produce more accurate soil moisture fields.

Accurate soil moisture is important for seasonal forecasts (Ferranti and Viterbo), climate modelling (Koster et al.), extreme weather (droughts, heat waves, floods), water management, agricultural applications, crop growth modelling, the carbon community, etc.

Introducing new observations is an efficient way to improve the forecast / analysis system:



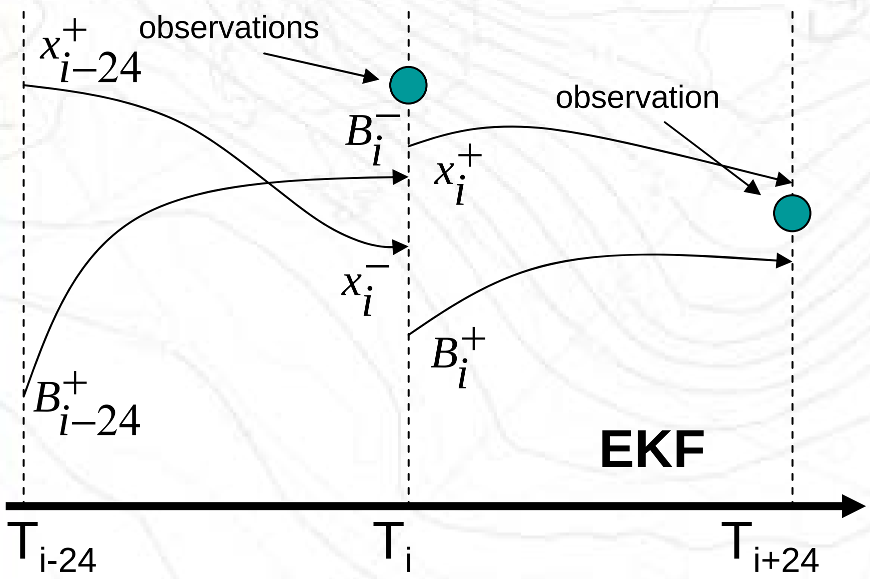
Extended Kalman Filter Analysis

Update at T_i:

$$\mathbf{K}_i = \mathbf{B}_i^- \mathbf{H}_i^T \left[\mathbf{H}_i \mathbf{B}_i^- \mathbf{H}_i^T + \mathbf{R}_i\right]^{-1}$$

$$\mathbf{x}_i^+ = \mathbf{x}_i^- + \mathbf{K}_i \left[\mathbf{y}_i - \mathbf{H}_i \mathbf{x}_k^-\right]$$

$$\mathbf{B}_i^+ = \mathbf{B}_i^- - \mathbf{K}_i \mathbf{H}_i \mathbf{B}_i^-$$



Propagation T_{i-24} to T_i:

$$\mathbf{x}_i^- = \mathbf{f}_{i-24}(\mathbf{x}_{i-24}^+)$$

$$\mathbf{B}_i^- = \mathbf{F}_{i-24} \mathbf{B}_{i-24}^+ \mathbf{F}_{i-24}^T + \mathbf{Q}_{i-24}$$

$$\left[\mathbf{F}_{i-24}\right]_{mn} = \left.\frac{\partial f_m}{\partial x_n}\right|_{x_{i-24}}$$

Propagation T_i to T_{i+24}:

$$\mathbf{x}_{i+24}^- = \mathbf{f}_i(\mathbf{x}_i^+)$$

$$\mathbf{B}_{i+24}^- = \mathbf{F}_i \mathbf{B}_i^+ \mathbf{F}_i^T + \mathbf{Q}_i$$

$$\left[\mathbf{F}_i\right]_{mn} = \left.\frac{\partial f_m}{\partial x_n}\right|_{x_i}$$

- The standard KF is the optimal sequential data assimilation method for linear dynamics and measurement processes with Gaussian error statistics.
- The EKF is a variant that can be used for nonlinear problems.
- The EKF works sequentially, applying in turn a forecast step and an update step.
- Propagating the background error covariance matrix is computationally very demanding (and the limiting factor in NWP applications).
- In land surface applications, horizontal correlations are being neglected, which reduces the costs considerably.