

Data disaggregation and evapotranspiration modeling: a synergism between multi-spectral/multi-resolution remote sensing data

O. Merlin¹, V. Stefan¹, Y. Malbêteau¹, M. J.
Escorihuela², C. Rüdiger³, L. Jarlan¹



isardSAT[®]



MONASH University

Data disaggregation and evapotranspiration modeling

Introduction: the twin issues

- Objective: to combine available remote sensing data
 - Surface Soil Moisture (**SM**): SMOS/AMSR/SMAP
~10 km-60 km
 - Land surface Temperature (**LST**): MODIS/Landsat/ASTER
~100 m-1km
 - Green Vegetation Index (**GVI**), Surface Albedo (**SA**):
Formosat-2/Venus/Sentinel-2
~10 m-30 m
- Scale issue: data disaggregation
- ET-related variables: process understanding

Data disaggregation and evapotranspiration modeling

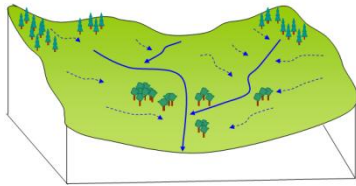
Introduction: data disaggregation



Global
Meteorology
Climatology



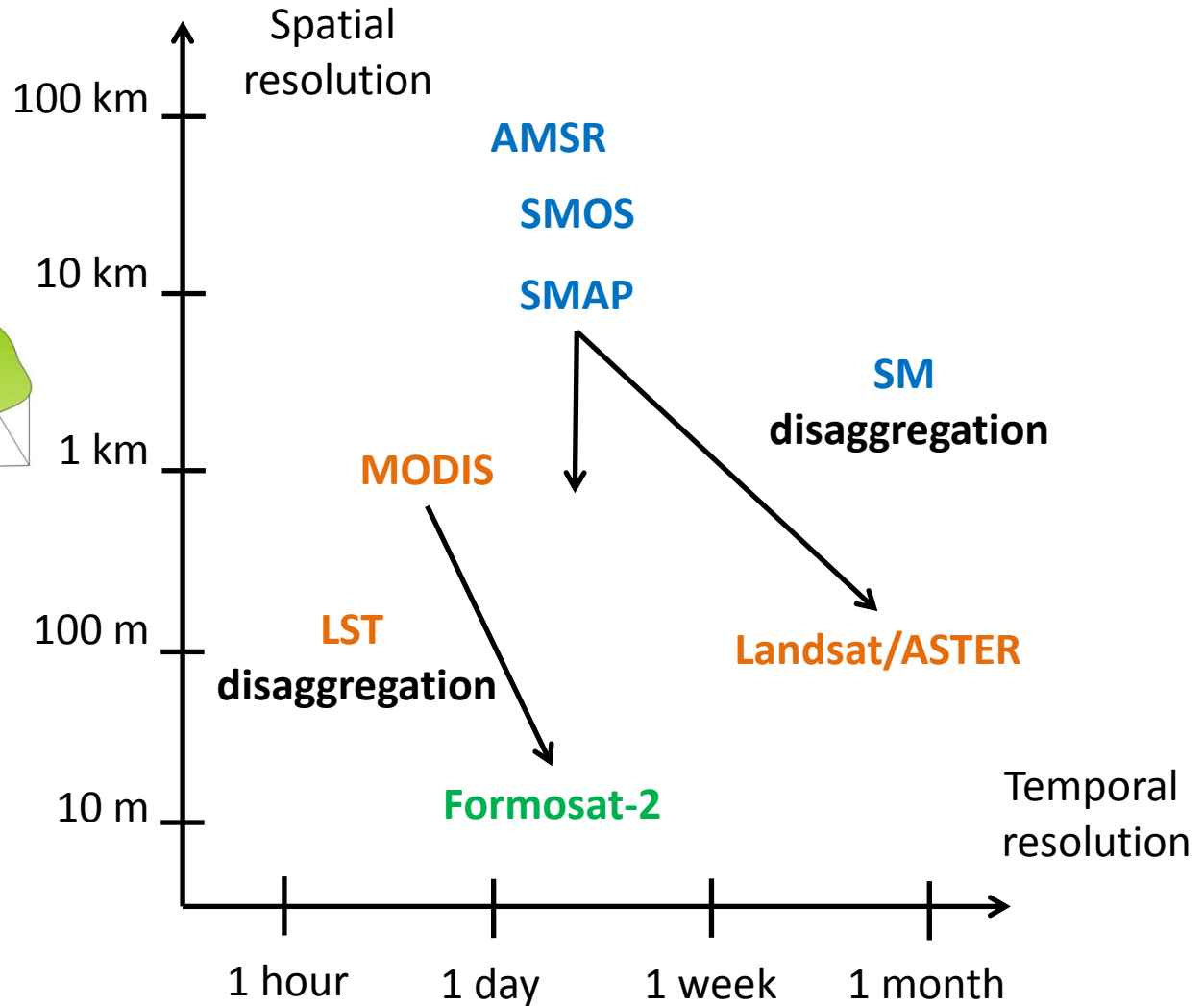
Catchment
Hydrology



Parcel
Agriculture

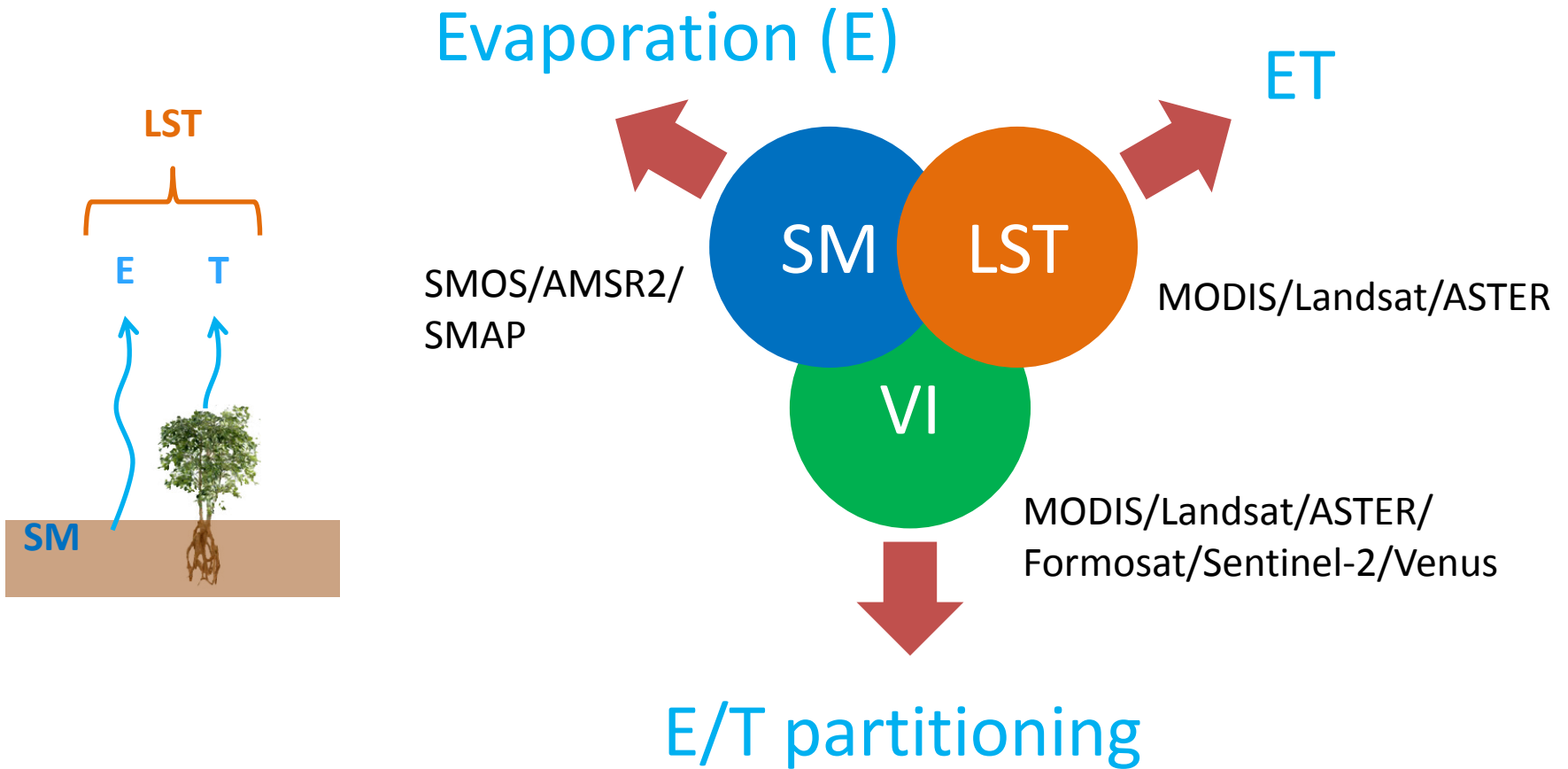


Station
Validation



Data disaggregation and evapotranspiration modeling

Introduction: ET modeling

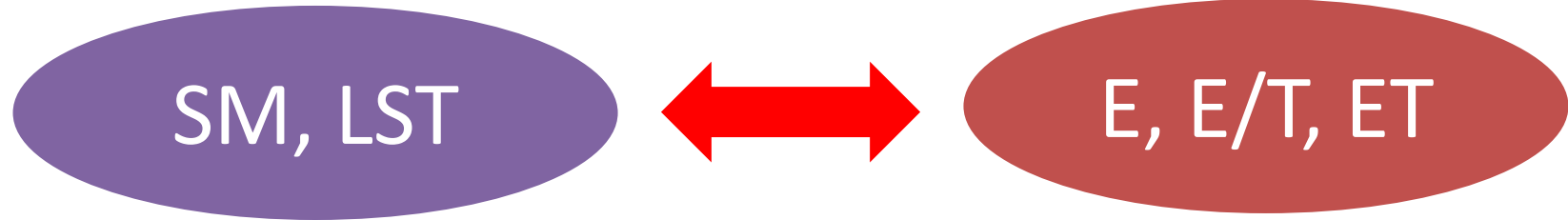


Data disaggregation and evapotranspiration modeling

Introduction

Data disaggregation

ET modeling

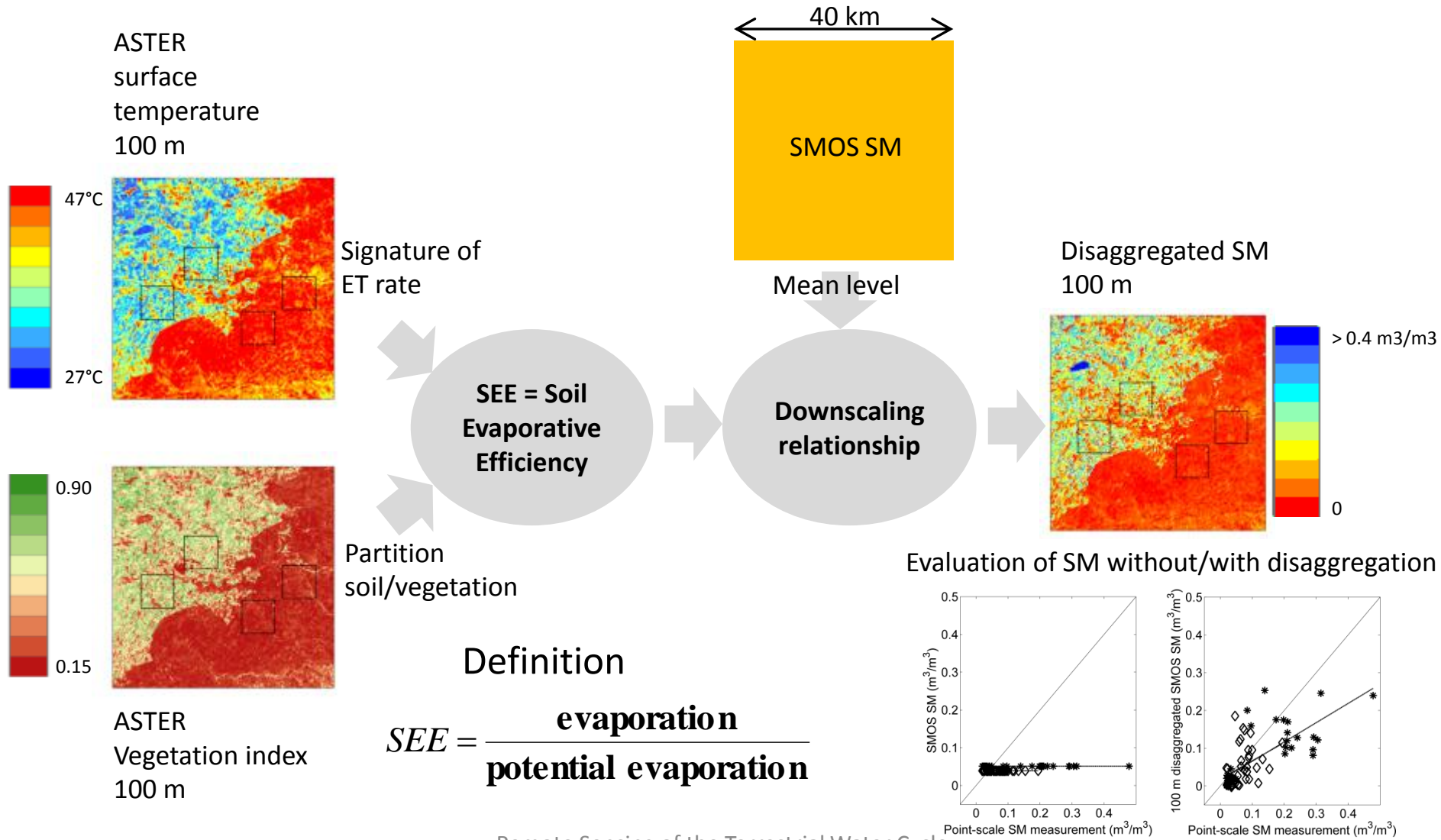


- SM disaggregation (DISPATCH-SM) and E modeling
- LST disaggregation (DISPATCH-LST) and ET modeling (SEB-1S)
- LST disaggregation (DISPATCH-LST) and ET modeling (SEB-4S)



Data disaggregation and evapotranspiration modeling

DISPATCH-SM – Basic principle





Data disaggregation and evapotranspiration modeling

DISPATCH-SM – Basic equation

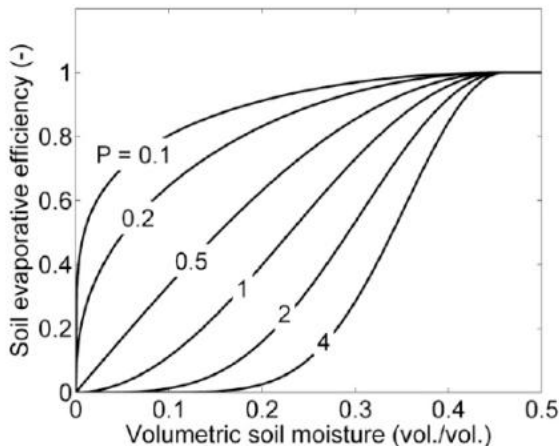
DISaggregation based on **Physical** and **Theoretical** scale Change
(Merlin et al., 2012b, 2013a)

SMOS data
40 km (0.5°) resolution
6 am/ 6 pm

SEE model

MODIS data
1 km (0.01°) resolution
10:30 am/ 1:30 pm

$$SM_{HR,i} = SM_{SMOS} + \left(\frac{\partial SEE_{mod}}{\partial SM} \right)_{SMOS}^{-1} \times \left(SEE_{HR,i} - \frac{1}{N} \sum_{j \in SMOS} SEE_{HR,j} \right)$$



$$SEE_{mod} = \frac{SM}{SM_p} \quad (\text{Manabe 1969})$$

$$SEE_{mod} = [0.5 - 0.5 \cos(\pi SM / SM_{fc})]^2 \quad (\text{Pielke 1992})$$

$$SEE_{mod} = [0.5 - 0.5 \cos(\pi SM / SM_{sat})]^P \quad (\text{Merlin et al., 2011})$$

Data disaggregation and evapotranspiration modeling

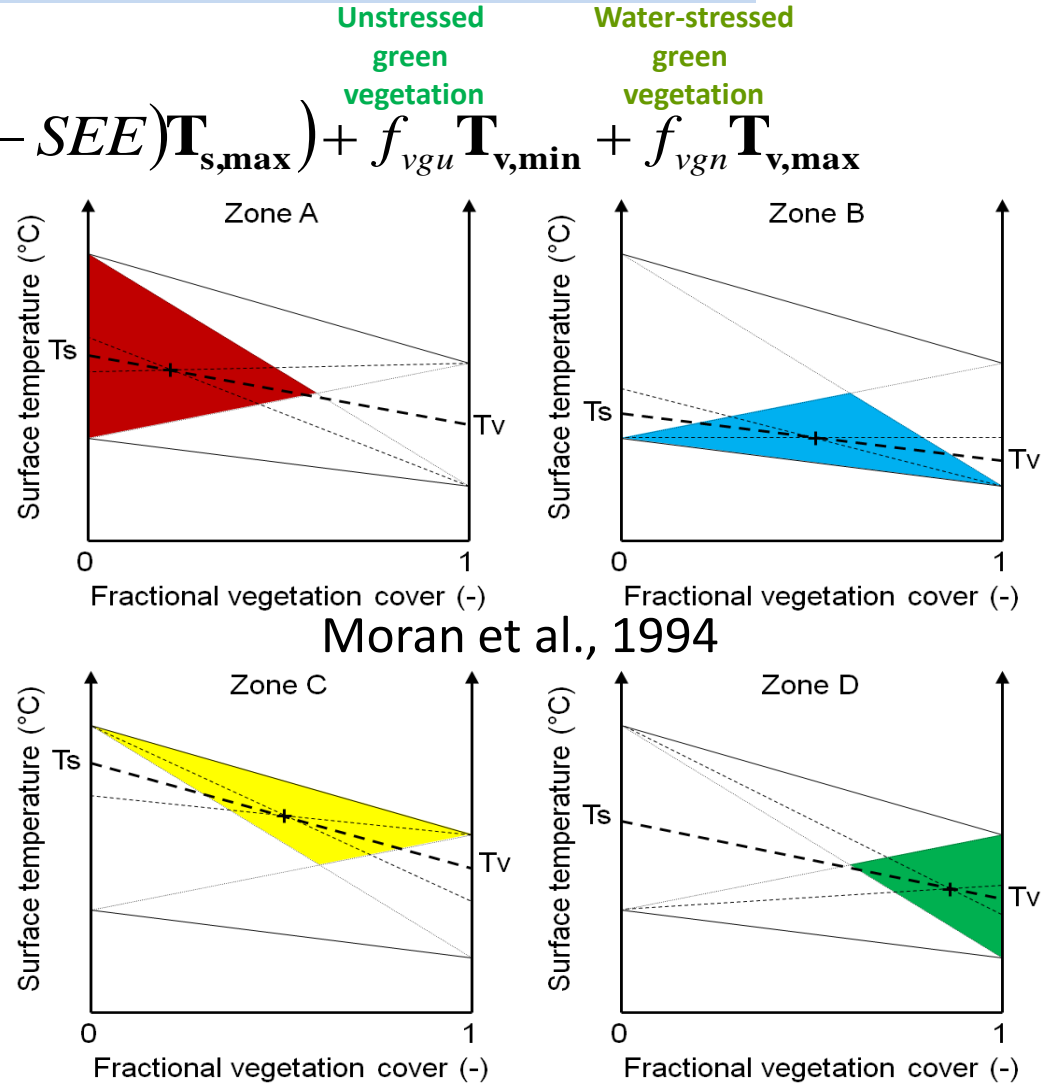
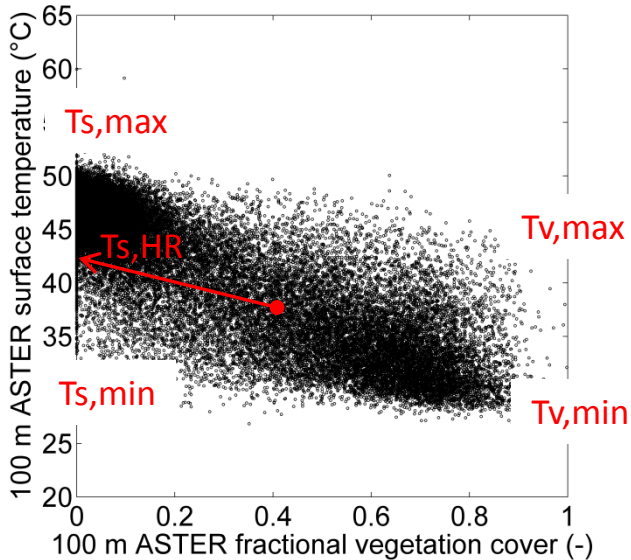
DISPATCH-SM – Estimating SEE



$$T_{mod} = f_s (SEE T_{s,min} + (1 - SEE) T_{s,max}) + f_{vgu} T_{v,min} + f_{vgn} T_{v,max}$$

Assumption

$$SEE_{HR,i} = \frac{T_{s,max} - T_{s,i}}{T_{s,max} - T_{s,min}}$$



Moran et al., 1994

Data disaggregation and evapotranspiration modeling

DISPATCH-SM – Validation at 3 km resolution

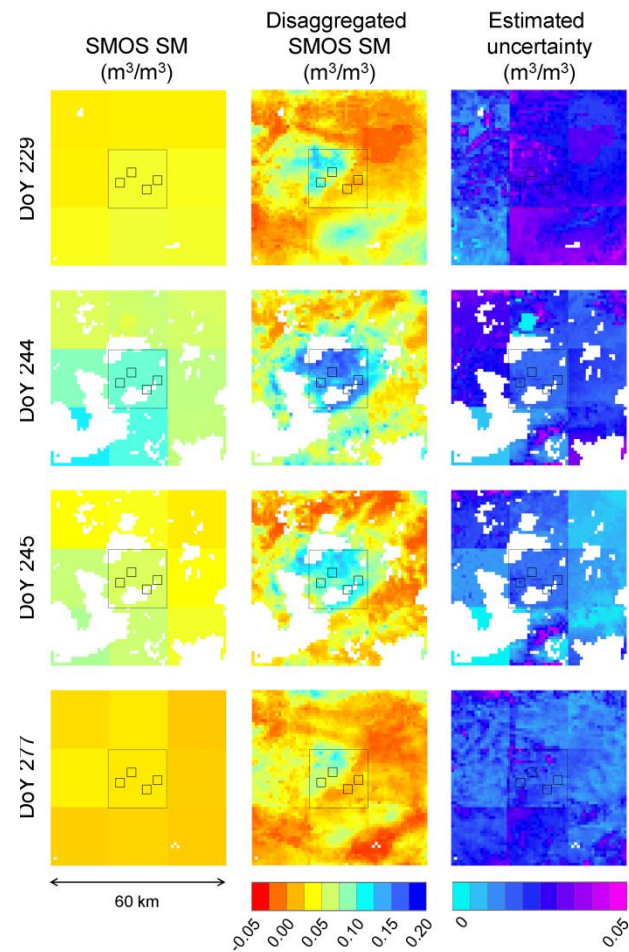
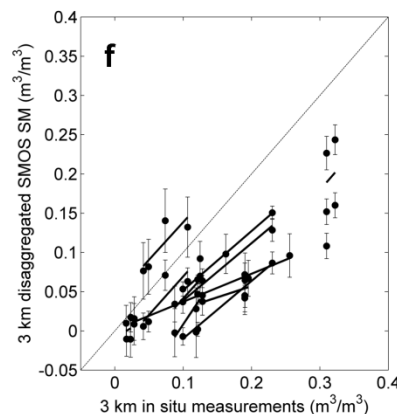
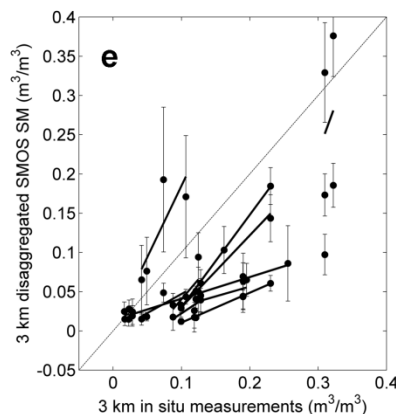
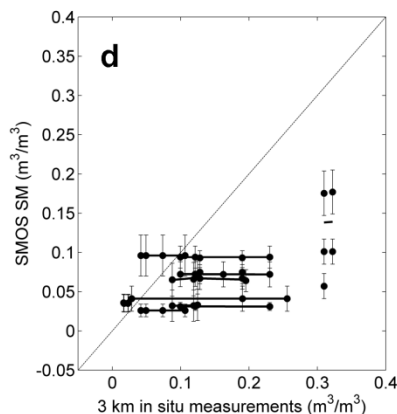
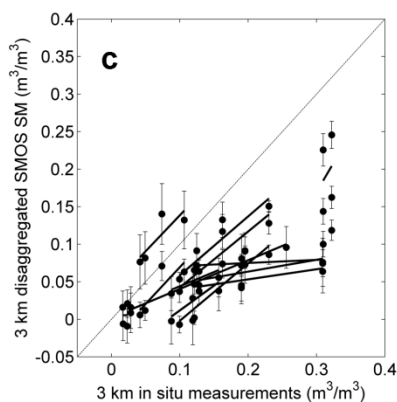
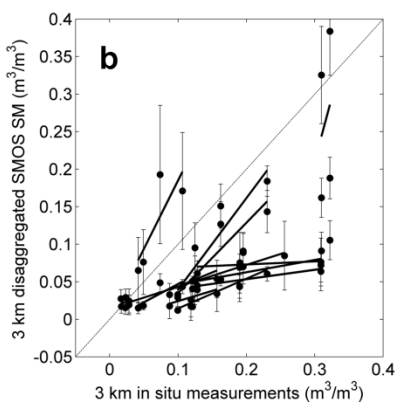
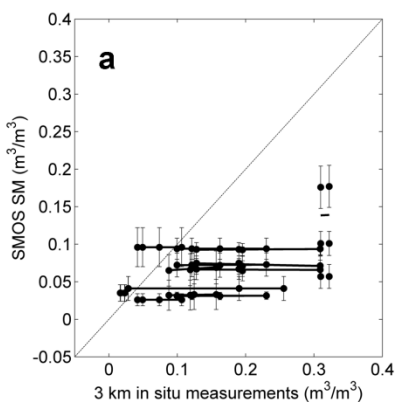


Disaggregated SMOS data

SMOS data

Daily calibration

Yearly calibration

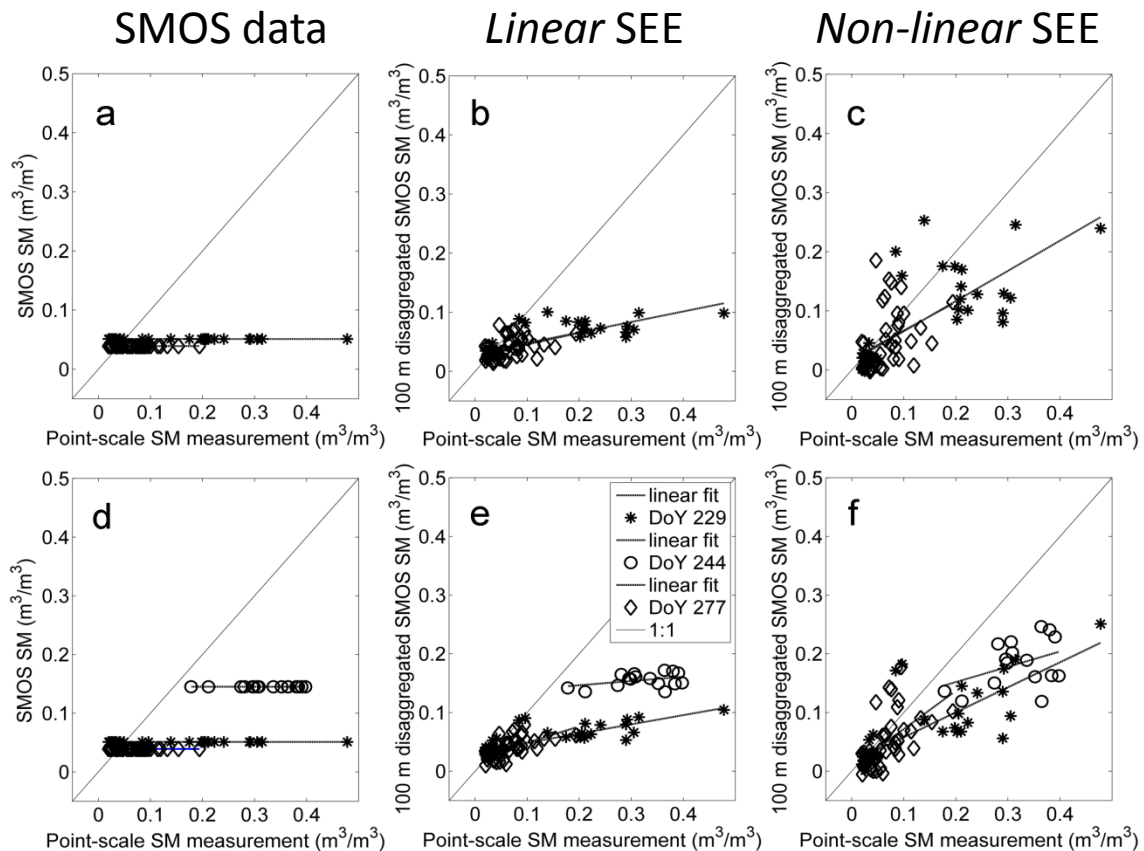


Data disaggregation and evapotranspiration modeling

DISPATCH-SM – Validation at 100 m resolution

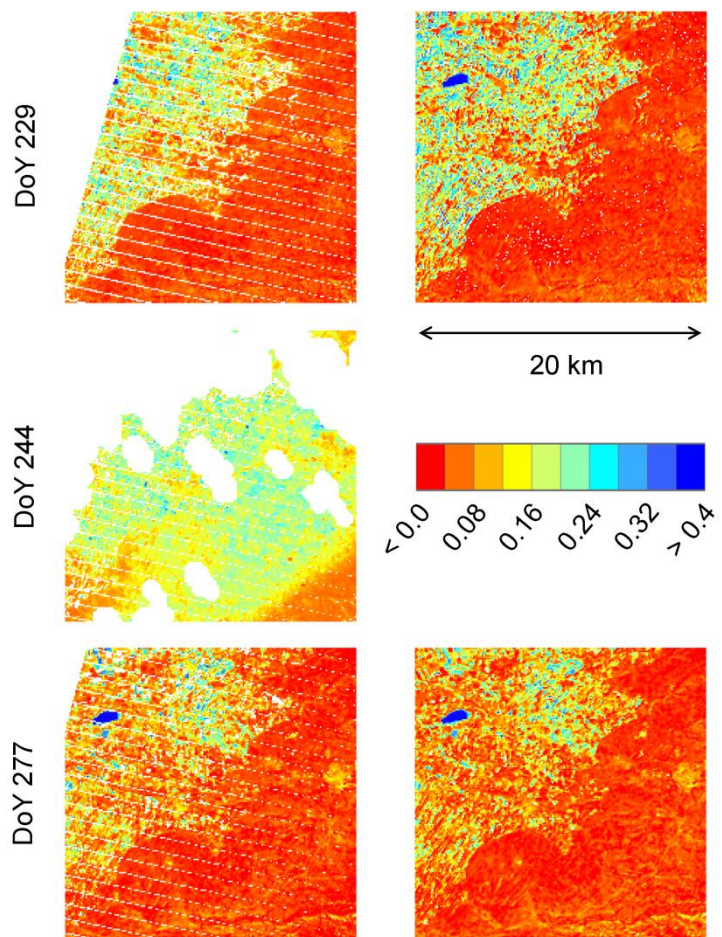


Disaggregated SMOS data



SMOS SM disaggregated using Landsat data (m^3/m^3)

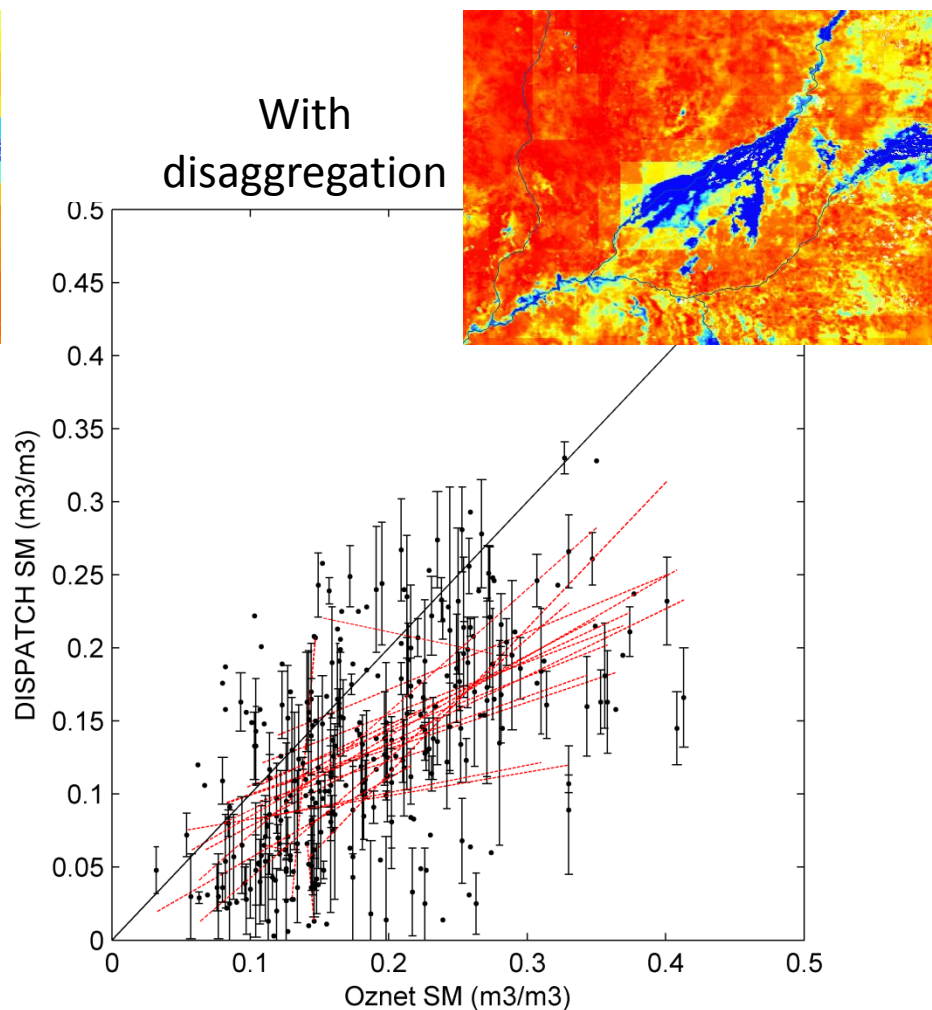
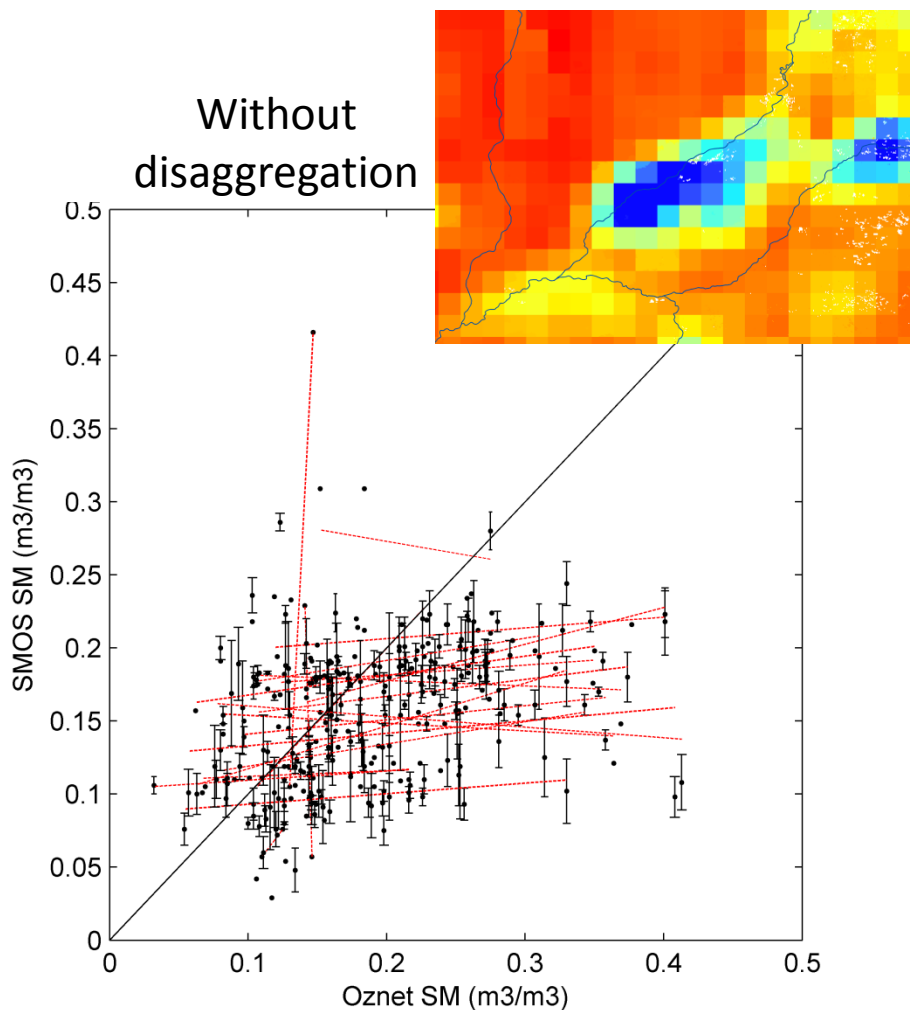
SMOS SM disaggregated using ASTER data (m^3/m^3)





Data disaggregation and evapotranspiration modeling

DISPATCH-SM – Validation in South-eastern Australia



Data disaggregation and evapotranspiration modeling

DISPATCH-LST: Disaggregation of LST data

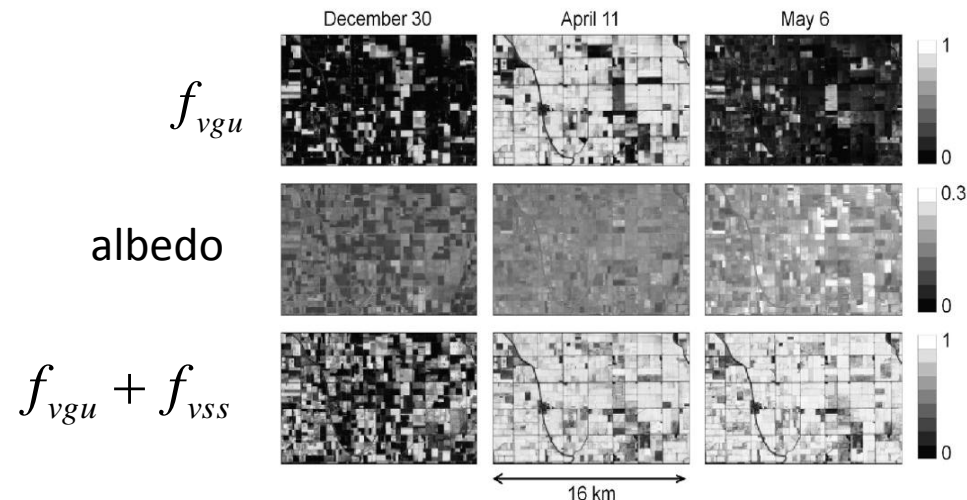
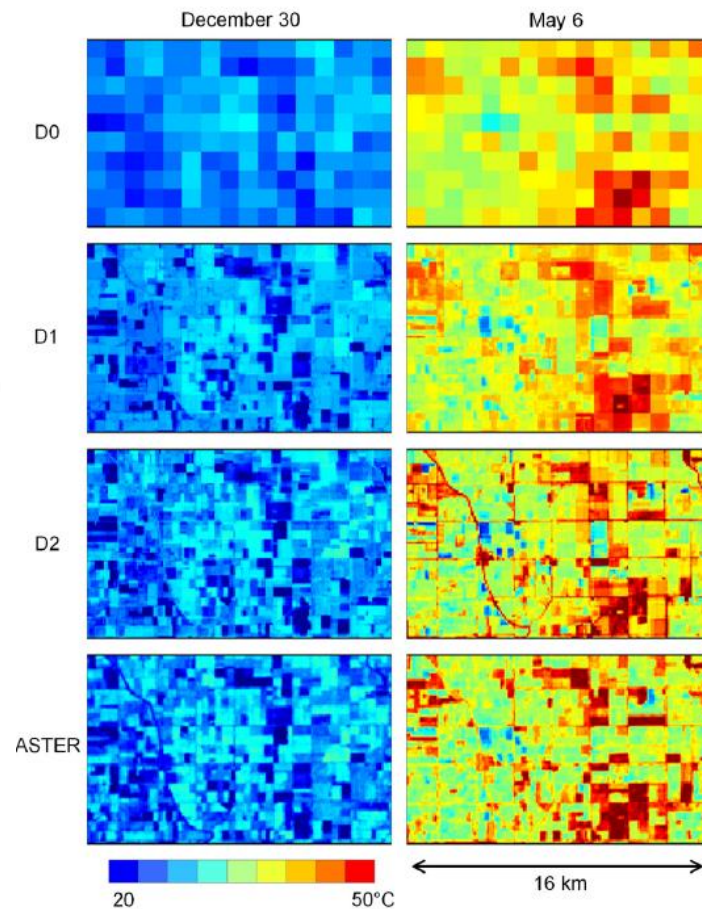
$$T_{mod} = f_s \frac{T_{s,min} + T_{s,max}}{2} + f_{vgu} T_{v,min} + f_{vss} T_{v,max}$$

Bare soil Unstressed green vegetation Senescent vegetation

$$T_{HR}^{(D0)} = T_{MODIS}$$

$$T_{HR}^{(D1)} = T_{MODIS} + a_1 \times (f_{vgu} - \langle f_{vgu} \rangle_{MODIS})$$

$$T_{HR}^{(D2)} = T_{MODIS} + a_1^{proj} \times (f_{vgu}^{proj} - \langle f_{vgu}^{proj} \rangle_{MODIS})$$



Disaggregation of MODIS surface temperature over an agricultural area using a time series of Formosat-2 images.

Merlin O., Duchemin B., Hagolle O., Frédéric J., Coudert B., Chehbouni A., Dedieu G., Garatuza J. and Kerr Y., *Remote Sensing of Environment*, 114, pp. 2500-2512, (2010b).

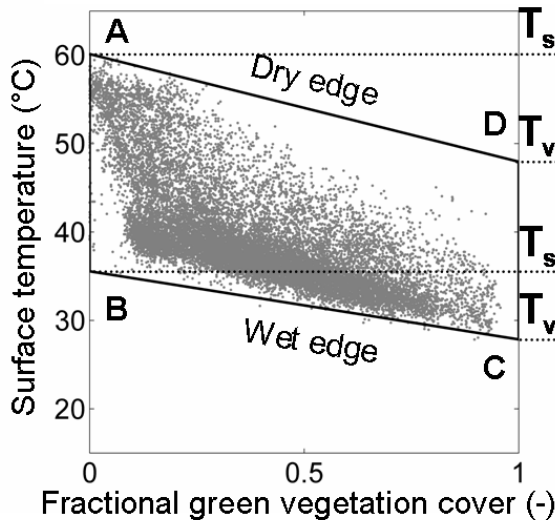


Data disaggregation and evapotranspiration modeling

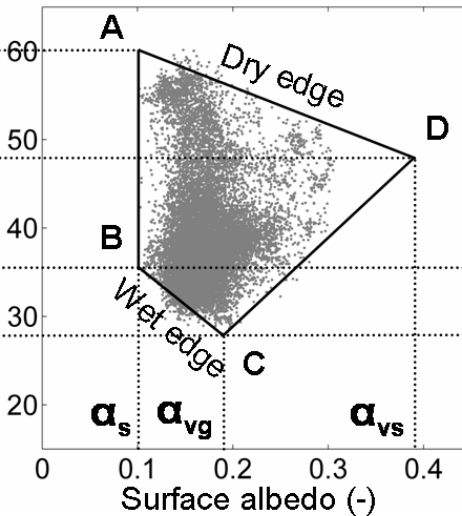
SEB-1S: a new ET model based on LST/GVI/SA

Monosource (1S) Surface Energy Balance model (SEB-1S):
A synergy between the LST-GVI and LST-SA spaces

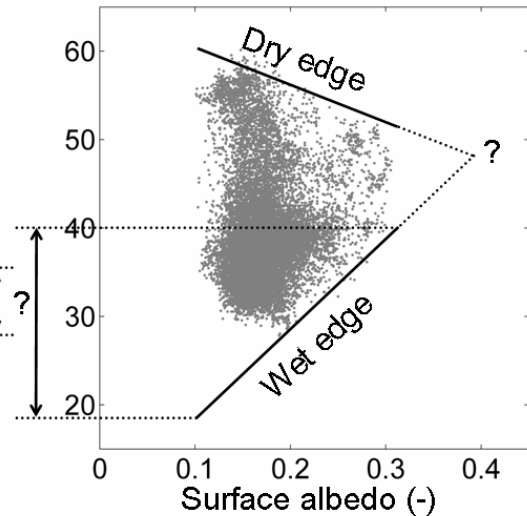
WDI (Moran et al., 1994)



SEB-1S



S-SEBI (Roerink et al., 2000)



An original interpretation of the wet edge of the surface temperature-albedo space to estimate crop evapotranspiration (SEB-1S), and its validation over an irrigated area in north-western Mexico, O. Merlin, Hydrol. Earth Syst. Sci., 17, 3623–3637, 2013b.

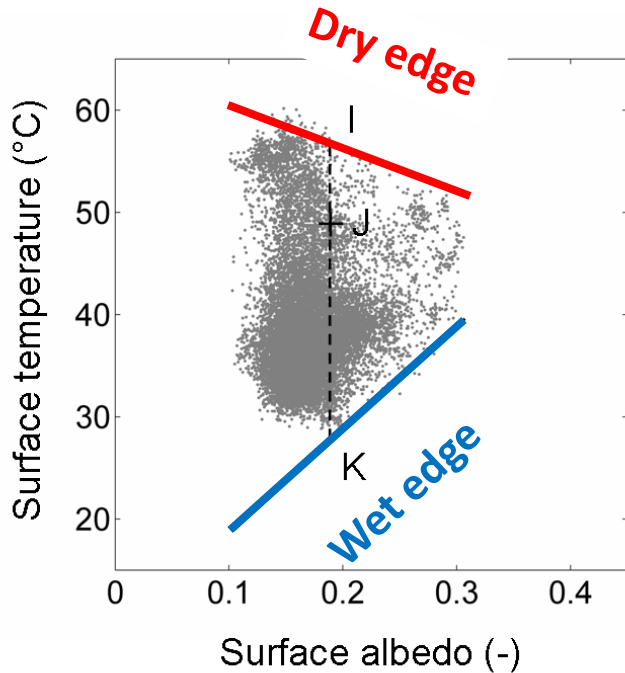
Data disaggregation and evapotranspiration modeling

SEB-1S: a new interpretation of the LST-SA space

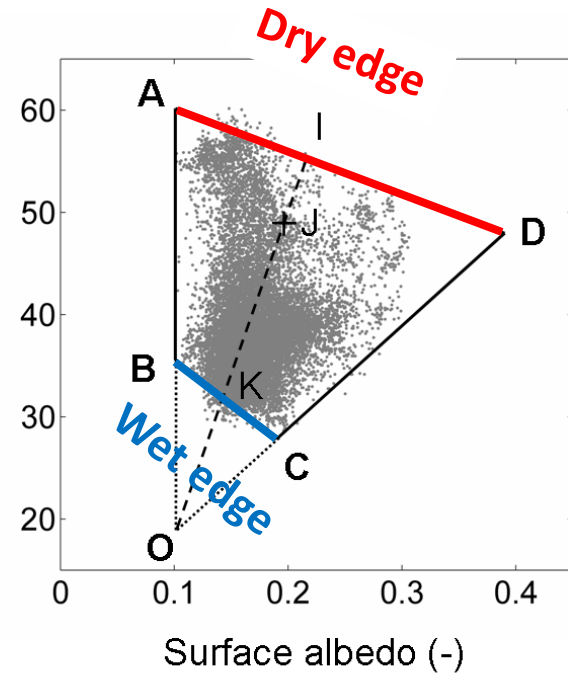


Estimation of the Evaporative Fraction: $EF = LE/(H+LE) = IJ/IK$

S-SEBI



SEB-1S

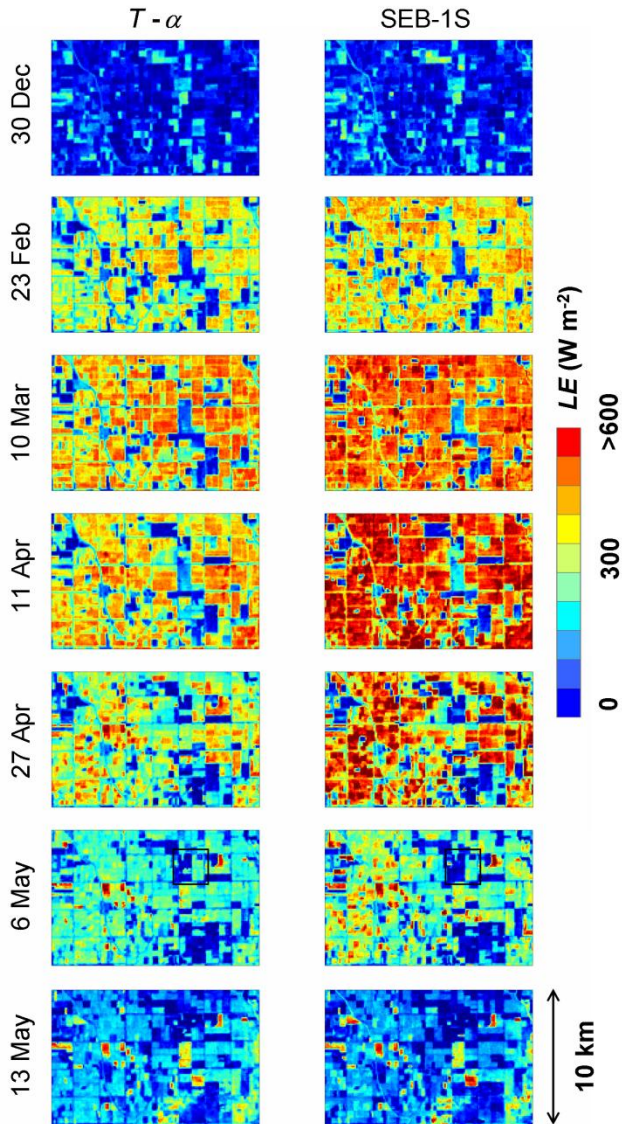


An original interpretation of the wet edge of the surface temperature-albedo space to estimate crop evapotranspiration (SEB-1S), and its validation over an irrigated area in north-western Mexico, O. Merlin, Hydrol. Earth Syst. Sci., 17, 3623–3637, 2013b.

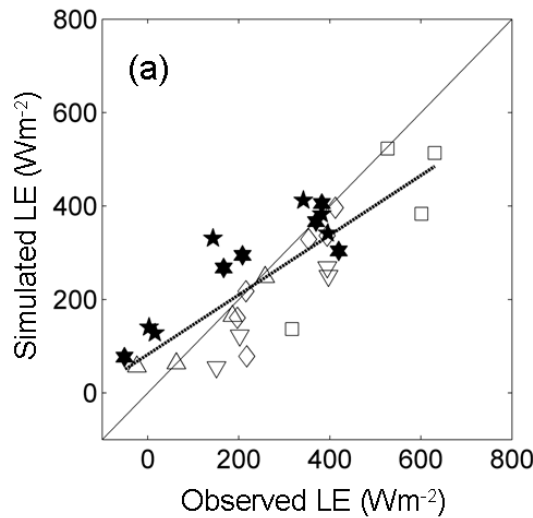


Data disaggregation and evapotranspiration modeling

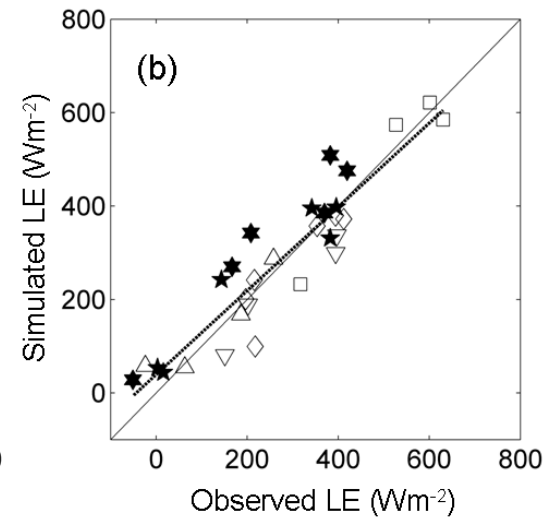
SEB-1S: Validation in North-western Mexico



$R = 0.82$
 RMSD = $100 W m^{-2}$



$R = 0.93$
 RMSD = $65 W m^{-2}$



□ 1 ◇ 2 △ 3 ▽ 4 ★ 5 ★ 6 — 1:1 - - - fit

S-SEBI

SEB-1S

Data disaggregation and evapotranspiration modeling

DISPATCH-LST: Disaggregation of LST data

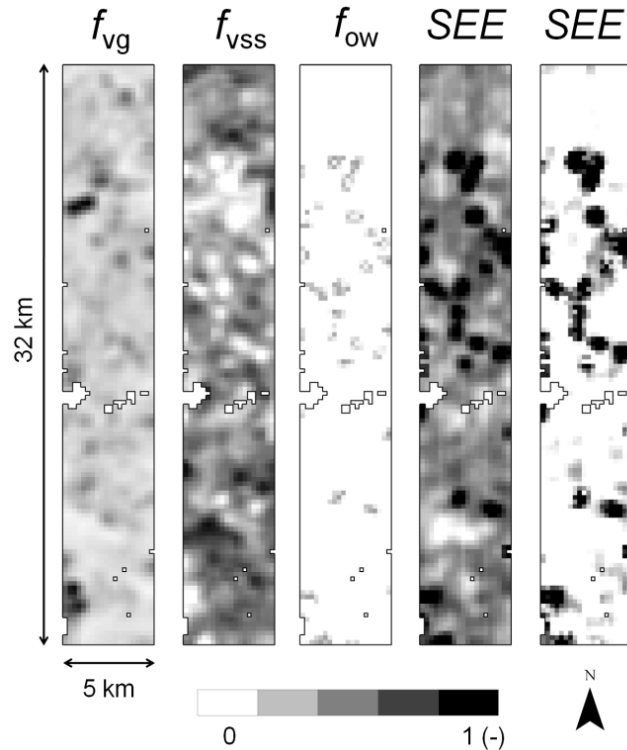
$$T_{\text{mod}} = f_{\text{ow}} \mathbf{T}_{\text{v,min}} + f_s \left(\text{SEE} \mathbf{T}_{\text{s,min}} + (1 - \text{SEE}) \mathbf{T}_{\text{s,max}} \right) + f_{\text{vgu}} \mathbf{T}_{\text{v,min}} + f_{\text{vss}} \mathbf{T}_{\text{v,max}}$$

Open water

Bare soil

Unstressed green vegetation

Senescent vegetation



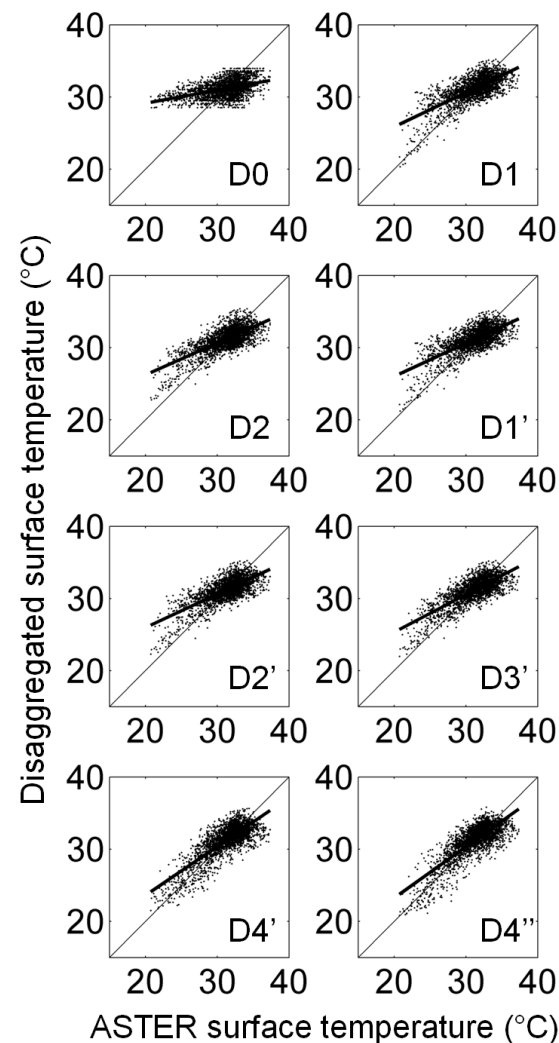
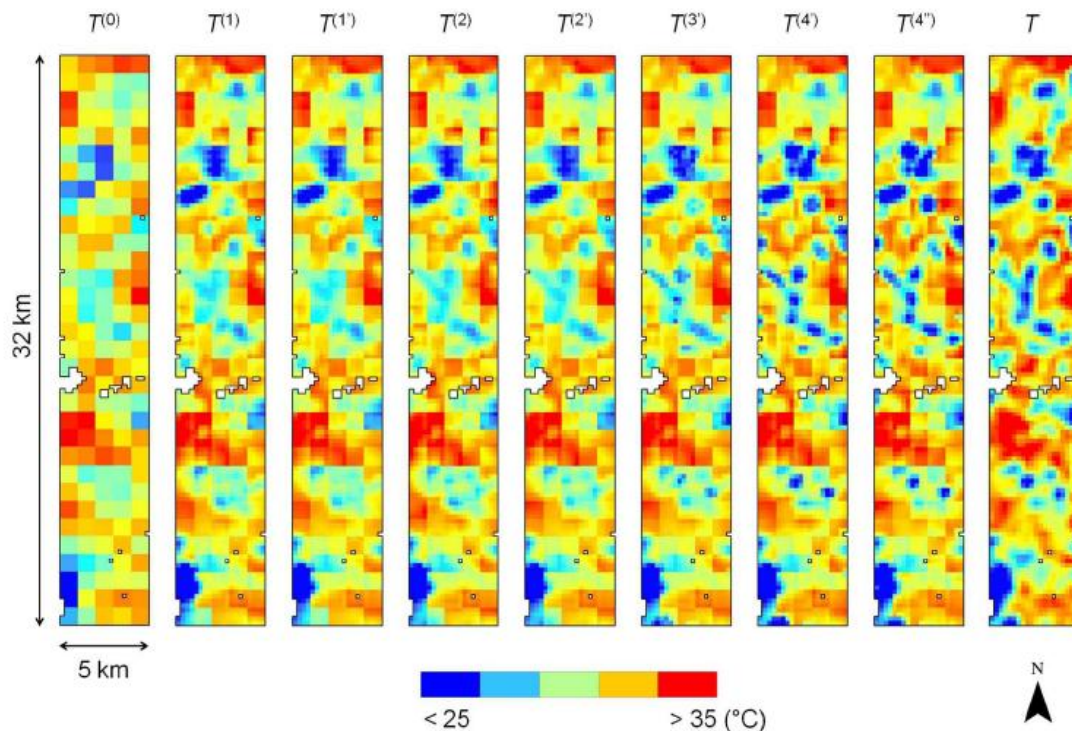
Multi-dimensional disaggregation of land surface temperature using high-resolution red, near-infrared, shortwave-infrared and microwave-L bands, Merlin O., F. Jacob, J.-P. Wigneron, J. Walker and G. Chehbouni, *IEEE Transactions on Geoscience and Remote Sensing*, 50 (5), pp. 1864-1880 (2012a).

Data disaggregation and evapotranspiration modeling

DISPATCH-LST: Adding dimensions



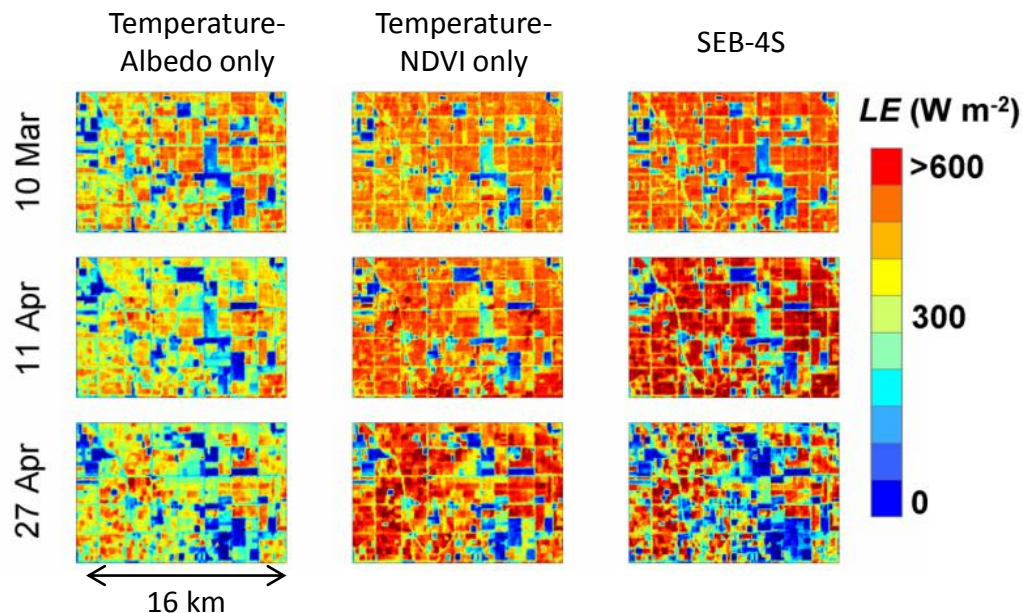
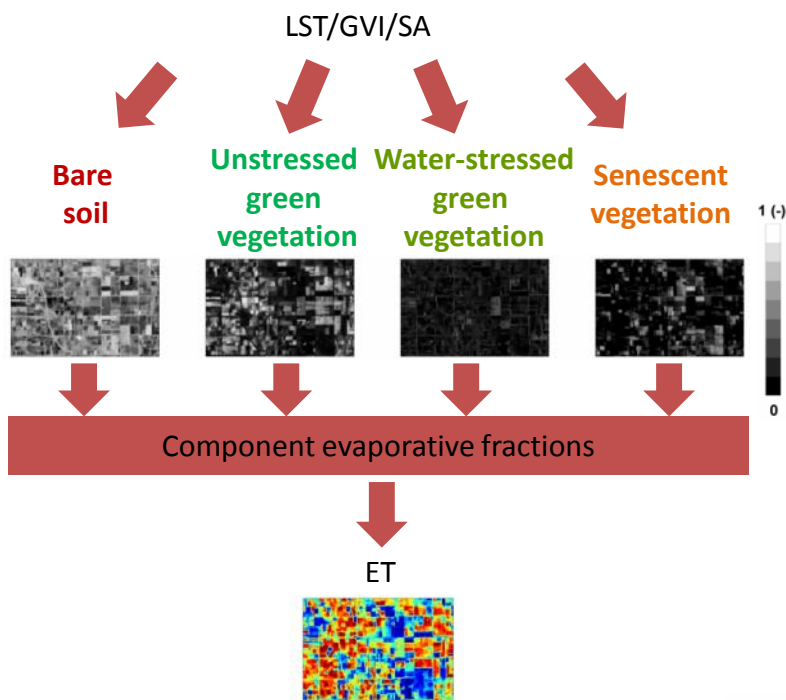
$$T_{HR}^{(i)} = T_{1km} + \Delta T_{mod}^{(i)}$$



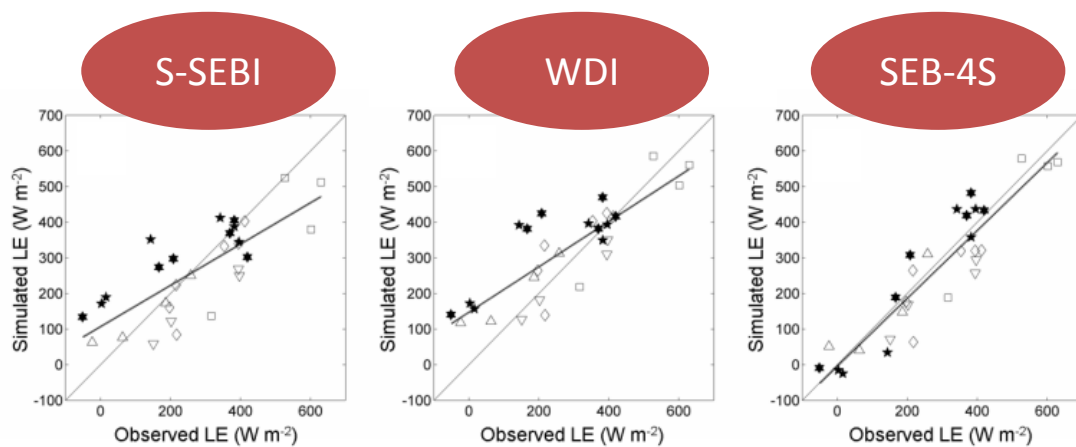
Multi-dimensional disaggregation of land surface temperature using high-resolution red, near-infrared, shortwave-infrared and microwave-L bands, Merlin O., F. Jacob, J.-P. Wigneron, J. Walker and G. Chehbouni, *IEEE Transactions on Geoscience and Remote Sensing*, 50 (5), pp. 1864-1880 (2012a).

Data disaggregation and evapotranspiration modeling

SEB-4S: Towards E/T partitioning



An image-based four-source surface energy balance model to estimate crop evapotranspiration from solar reflectance/thermal emission data (SEB-4S), Merlin O., J. Chirouze, A. Olioso, L. Jarlan, G. Chehbouni, G. Boulet, *Agricultural and Forest Meteorology*, 184 (2014) 188– 203.





Data disaggregation and evapotranspiration modeling

SEB-4S: Estimating component fractions

Bare soil

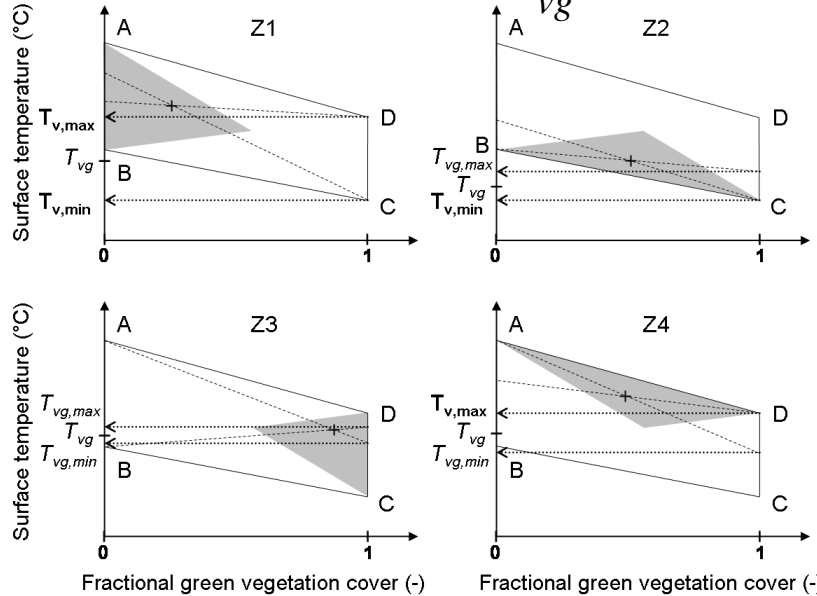
Unstressed green vegetation

Water-stressed green vegetation

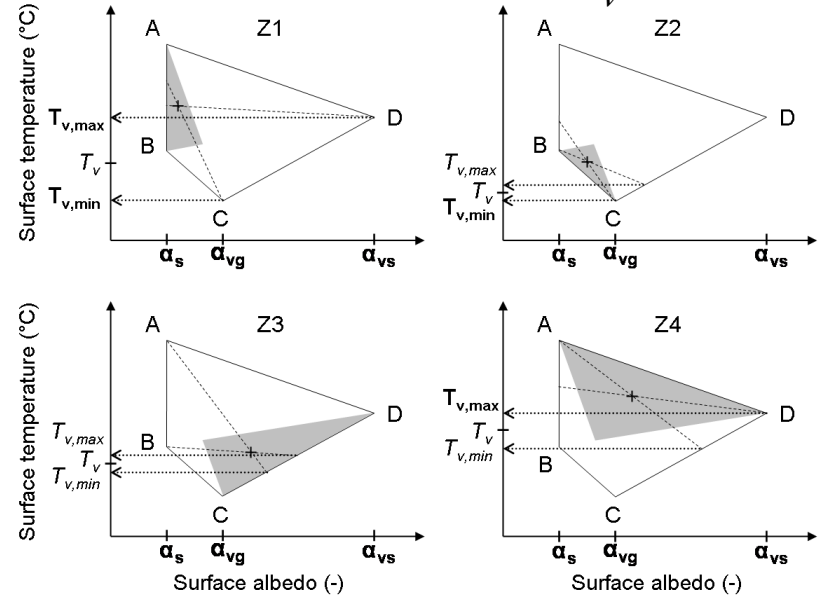
Senescent vegetation

$$T_{mod} = \underbrace{f_s (EF_s T_{s,min} + (1 - EF_s) T_{s,max})}_{f_s T_s} + \underbrace{f_{vgu} T_{v,min} + f_{vgn} T_{v,max}}_{f_{vg} T_{vg}} + f_{vss} T_{v,max}$$

Estimating T_{vg}



Estimating T_v



Conclusion



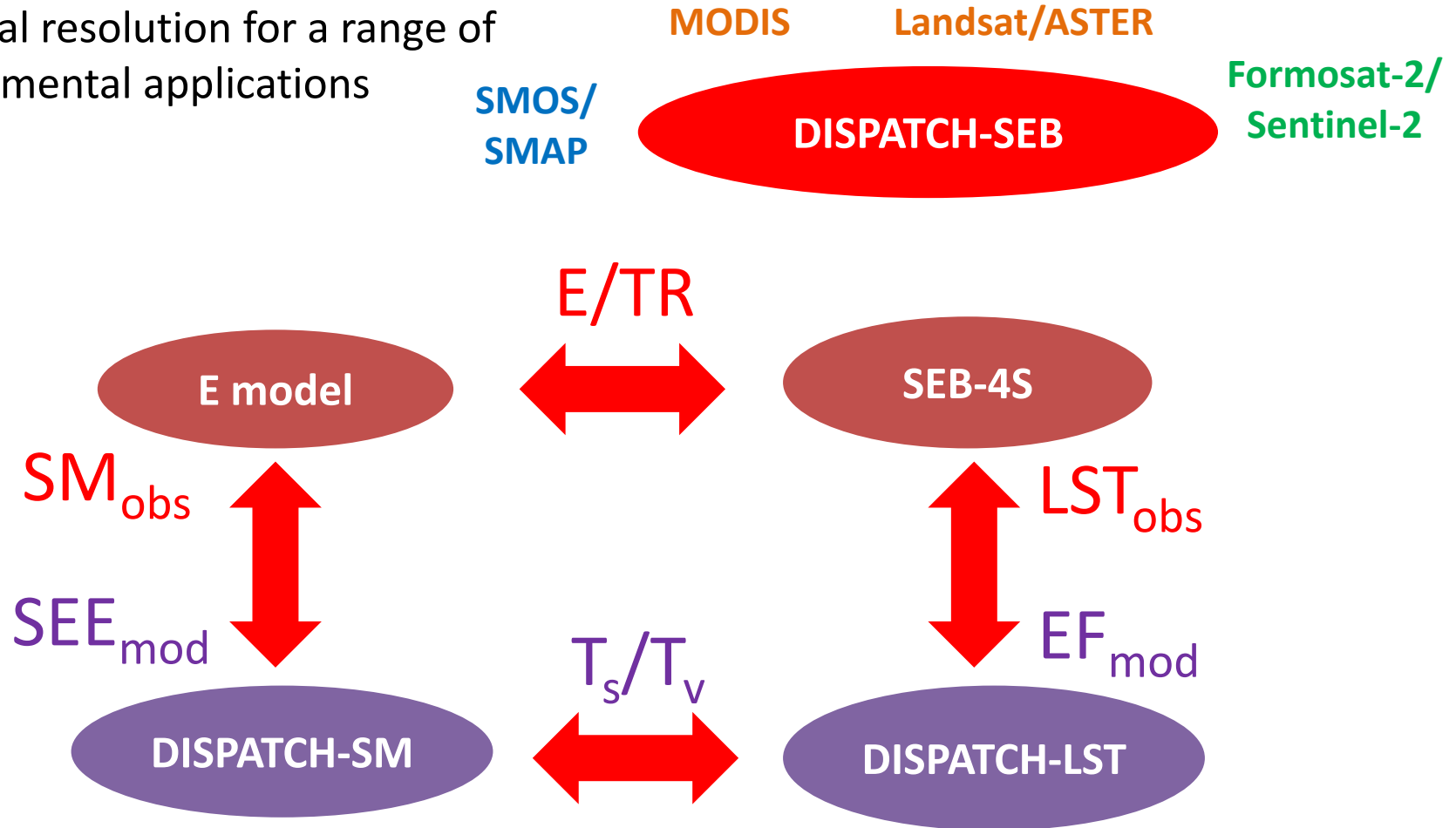
- Equivalence between data disaggregation and ET modeling:
Improvements in data downscaling methods result in advanced ET models and reciprocally
Improvements in ET modeling result in more accurate downscaling methods
- DISPATCH-SM (Merlin et al., 2012b, 2013a) based on E modeling (Merlin et al., 2011)
- SEB-1S (Merlin 2013b) and SEB-4S (Merlin et al., 2014) were derived from the same theoretical framework as previous downscaling methods for LST (Merlin et al. 2010; Merlin et al., 2012a)
- DISPATCH and SEB models are consistent with each other and may contribute to the development of a coupled approach...



Data disaggregation and evapotranspiration modeling

Conclusion

Towards LST/SM/E/TR at high spatio-temporal resolution for a range of environmental applications



Data disaggregation and evapotranspiration modeling

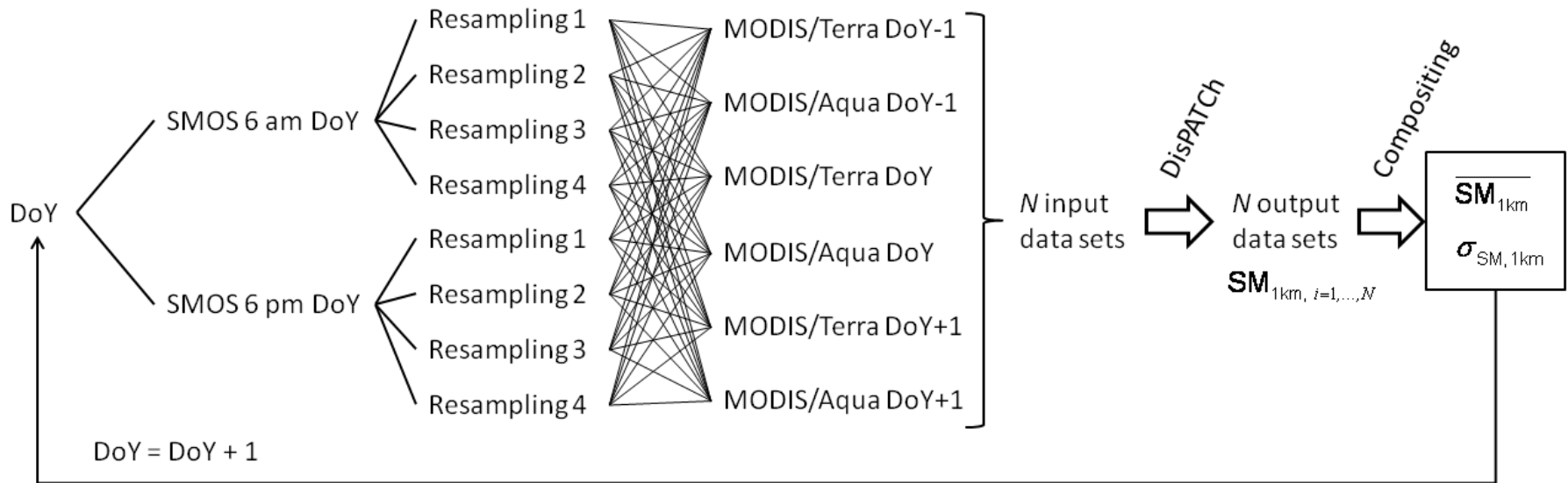


Thank you!



Data disaggregation and evapotranspiration modeling

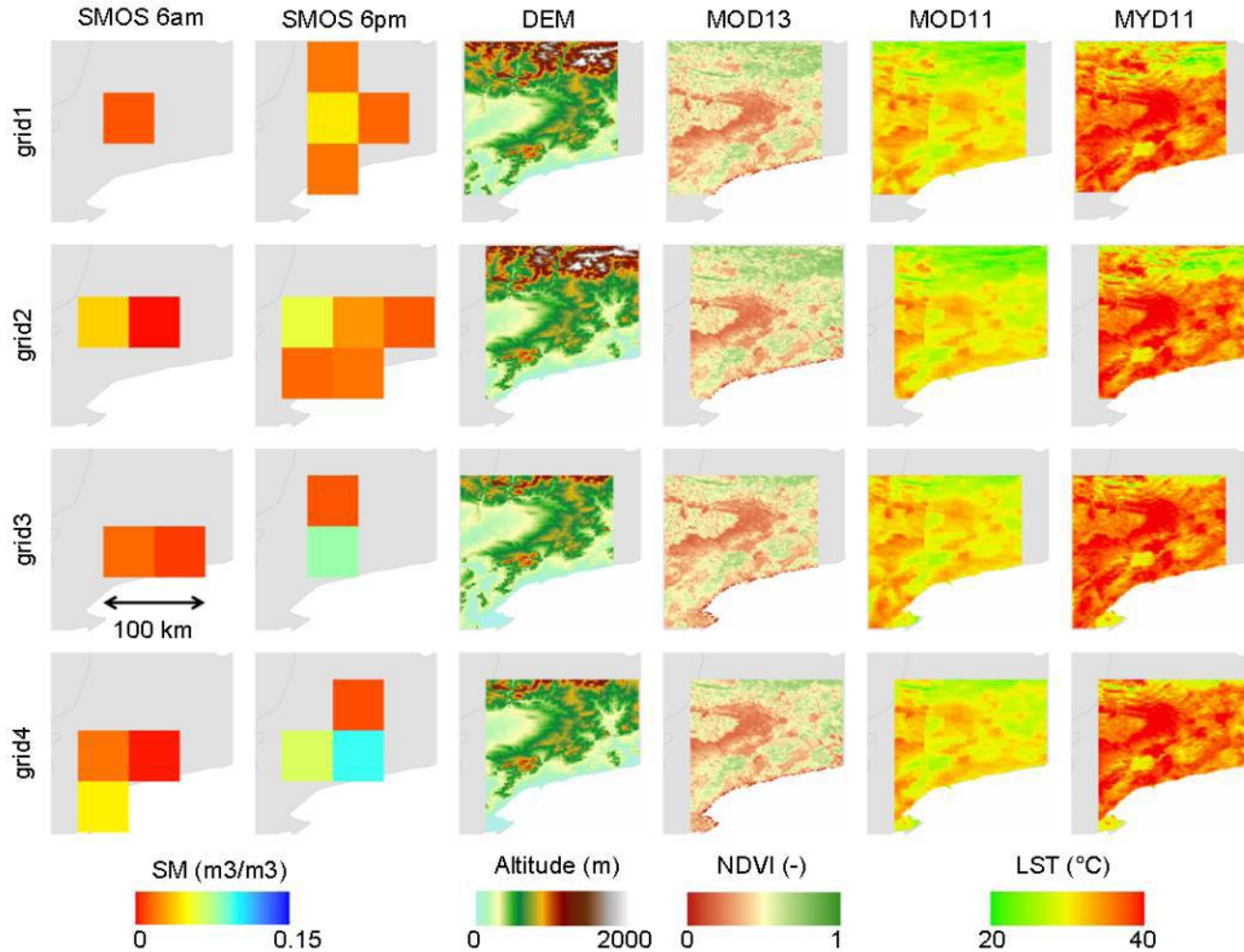
DISPATCH-SM – Input/output data





Data disaggregation and evapotranspiration modeling

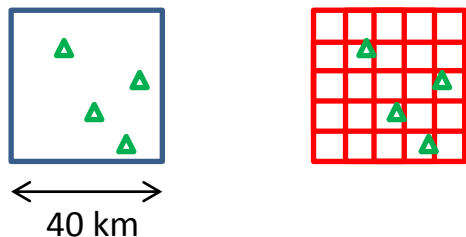
DISPATCH-SM – Input data sample





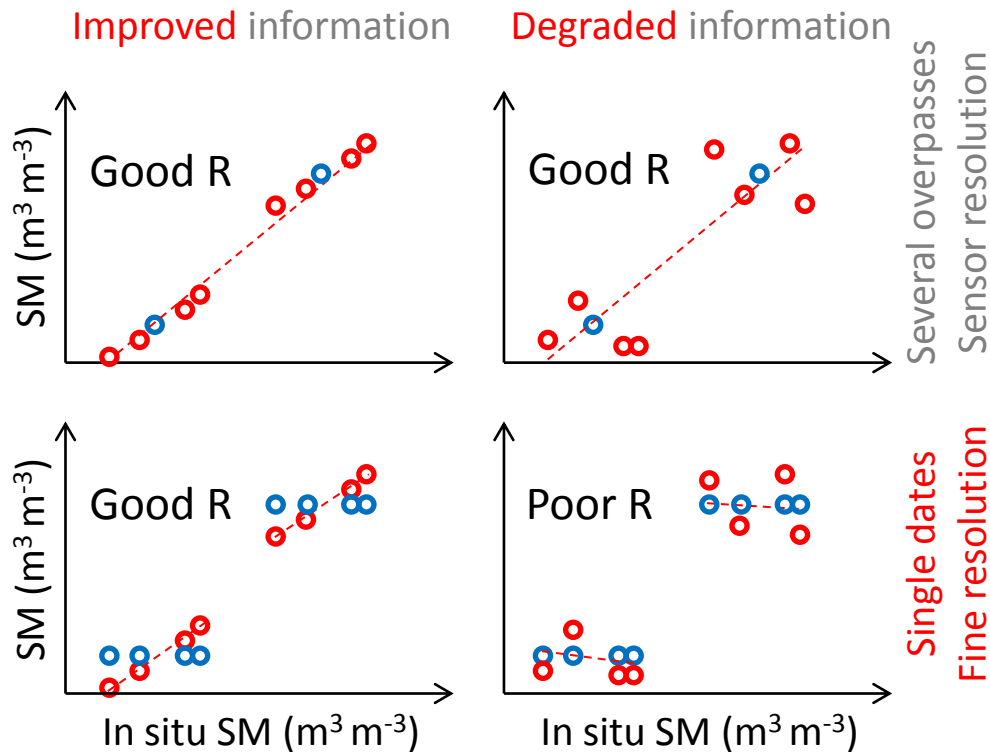
Data disaggregation and evapotranspiration modeling

DISPATCH-SM – Validation strategies



- Data accuracy depends on:
- the temporal information provided by low resolution data
 - the spatial information provided by low resolution data
 - the spatial information provided by the downscaling method

Compare for a given SMOS overpass and at fine scale disaggregated SM vs in situ meas. **and** low resolution data vs in situ meas.



Self-calibrated evaporation-based disaggregation of SMOS soil moisture: an evaluation study at 3 km and 100 m resolution in Catalunya, Spain, Merlin O., M. J. Escorihuela, M. A. Mayoral, O. Hagolle, A. Al Bitar, and Y. Kerr. *Remote Sensing of Environment*, 130, pp. 25-38, 2013.