Inversion of linear mixing model to retrieve component temperatures

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Outline

- **Theory**

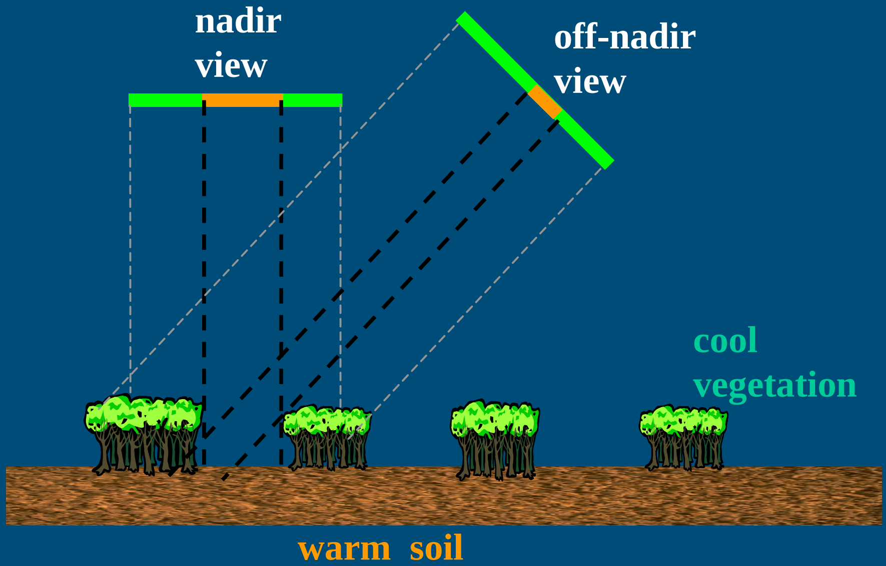
  from complex radiative transfer in heterogeneous canopies
  to a simple linear mixture model

- Retrieval of component temperatures using TOC brightness temperature
  - ground measurements
  - synthetic images

- Retrieval of component temperatures using TOA multi-spectral and multi-angular radiance measurements

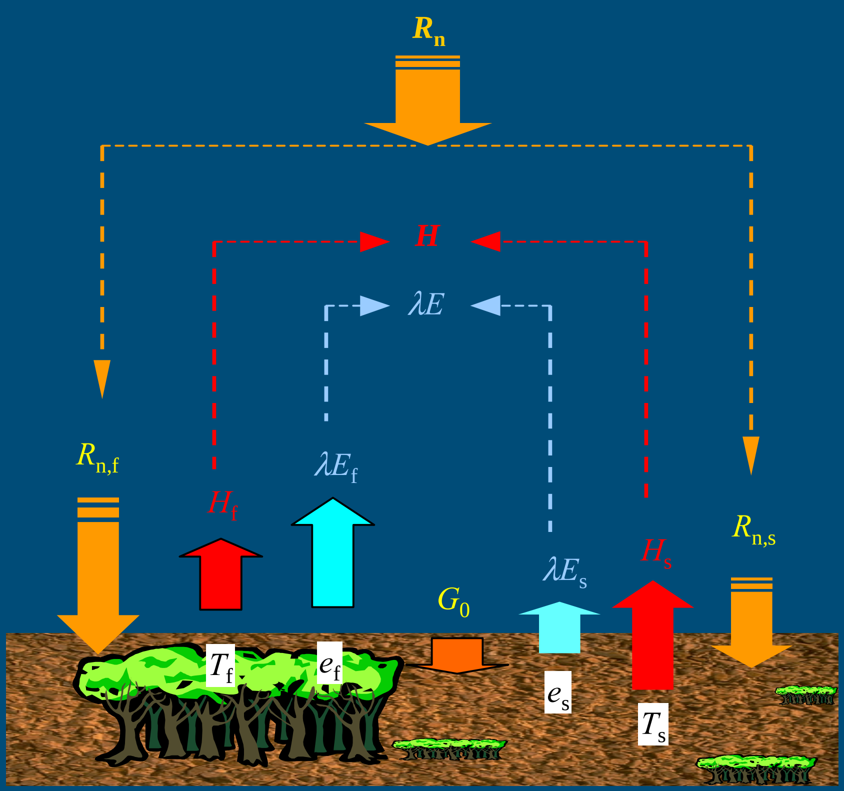
Background

- Most land surfaces are heterogeneous mixtures of foliage and soil
- The multiangular and multispectral measurements provide a possibility to derive components temperatures



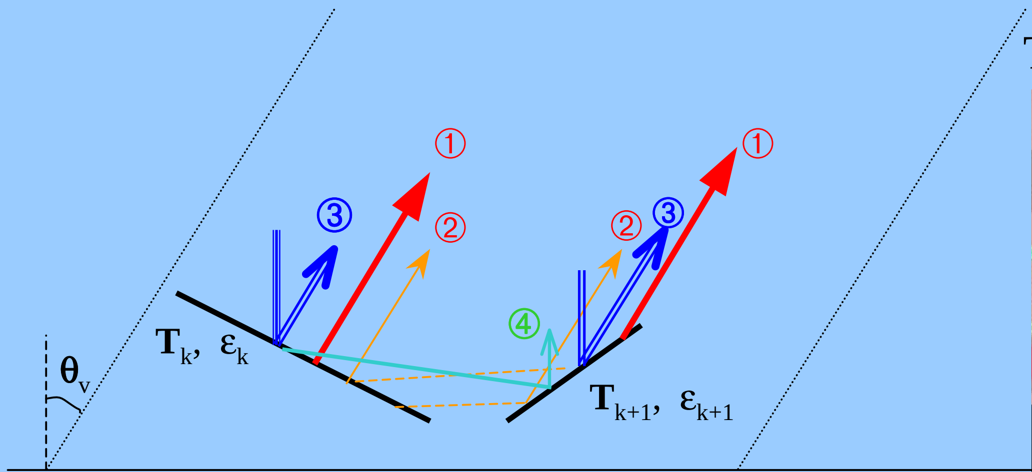
- Angular TIR measurements made by satellites - ATSR: quasi-simultaneous multispectral data from VIS to TIR regions at two view angles, 0 ° and 55°

- Estimates of the component temperatures of foliage and soil within a heterogeneous target can be used to improve the parameterization of heat transfer at heterogeneous land surfaces

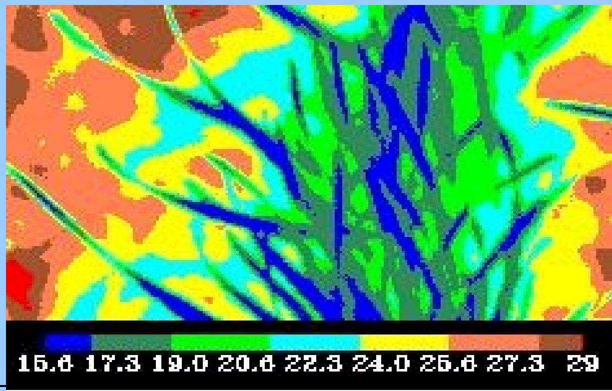


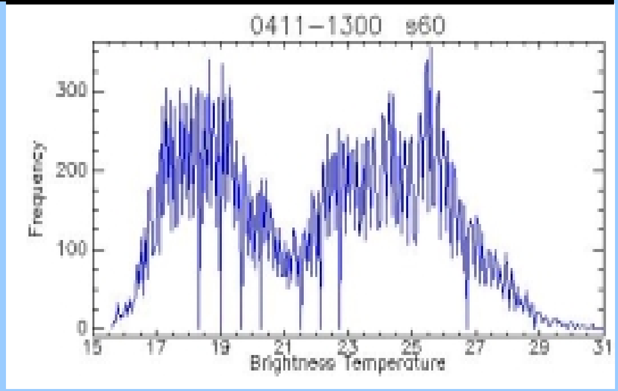
Modelling 1/3: TIR radiative transfer in soil-vegetation canopy

$$B\left[\lambda, T_{b0}(\theta_v, \varphi_v)\right] = \sum_{k=1}^{N_c}\left[f_k R_k(\lambda, T_k)\right] + \sum_{k=1}^{N_c}\left[f_k R'_k(\lambda)\right] + R_{atm}^{\downarrow}\uparrow + R_{atm}^{\downarrow}\uparrow'$$



T0 measured by thermal camera





Exitance of a canopy is a complex function of
- component emittance
- canopy structure

⇨ simple model

Modelling 2/3: Linear mixing model to retrieve two components temperatures: T_s and T_f

$$B[T_{b0}(\theta_v)] = f_s(\theta_v)\varepsilon_s B(T_s) + f_f(\theta_v)\varepsilon_f B(T_f)$$
$$+ f_s(\theta_v)(1-\varepsilon_s)(1-P_h)\varepsilon_f B(T_f) + f_f(\theta_v)(1-\varepsilon_f)(1-P_h)\varepsilon_s B(T_s)$$
$$+ f_s(\theta_v)[1-\varepsilon_s]R_{atm}^{\downarrow} + f_f(\theta_v)[1-\varepsilon_f]R_{atm}^{\downarrow}$$

$$\Rightarrow B[T_{b0}(\theta_v)] = f_s(\theta_v)\varepsilon_s'(\theta_v)B(T_s) + f_f(\theta_v)\varepsilon_f'(\theta_v)B(T_f)$$
$$+ f_s(\theta_v)[1-\varepsilon_s(\theta_v)]R_{atm}^{\downarrow} + f_f(\theta_v)[1-\varepsilon_f(\theta_v)]R_{atm}^{\downarrow}$$

Effective emissivity

$$\varepsilon_s'(\theta) = \{1 + (1-\varepsilon_f)(1-P_h)f_f(\theta_v)[f_s(\theta_v)]^{-1}\}\varepsilon_s$$
$$\varepsilon_f'(\theta) = \{1 + (1-\varepsilon_s)(1-P_h)f_s(\theta_v)[f_f(\theta_v)]^{-1}\}\varepsilon_f$$

Assumptions:

1) the canopy geometry is characterized by the component fractional cover;
2) The component fractional cover changes only with zenith view angle;
3) vegetation having an effective temperature (Tf) forms a uniform layer covering the soil surface having the effective temperature (Ts);
4) the soil and leaf surfaces are Lambertian.

Unknowns: Ts and Tf

Modelling 3/3: Estimate of fractional vegetation cover

1. Knowing canopy structure :
   LAI + LIDF + radiative transfer model:

$$F(\theta) = 1 - e^{(-k \frac{LAI}{\cos\theta})}$$

k : extinction coefficient

2. Stepwise multiple linear regression

$$F(\theta) = a_0(\theta_s,\theta) + \sum_{i=1}^{n} a_i(\theta_s,\theta)\rho_i(\theta_s,\theta,\Delta\phi)$$

a_i : regression coefficients
n : number of channels used in the range of visible to SWIR channels,
θ_s : solar zenith angle,
$\Delta\phi$: relative azimuth angle between sun and satellite direction

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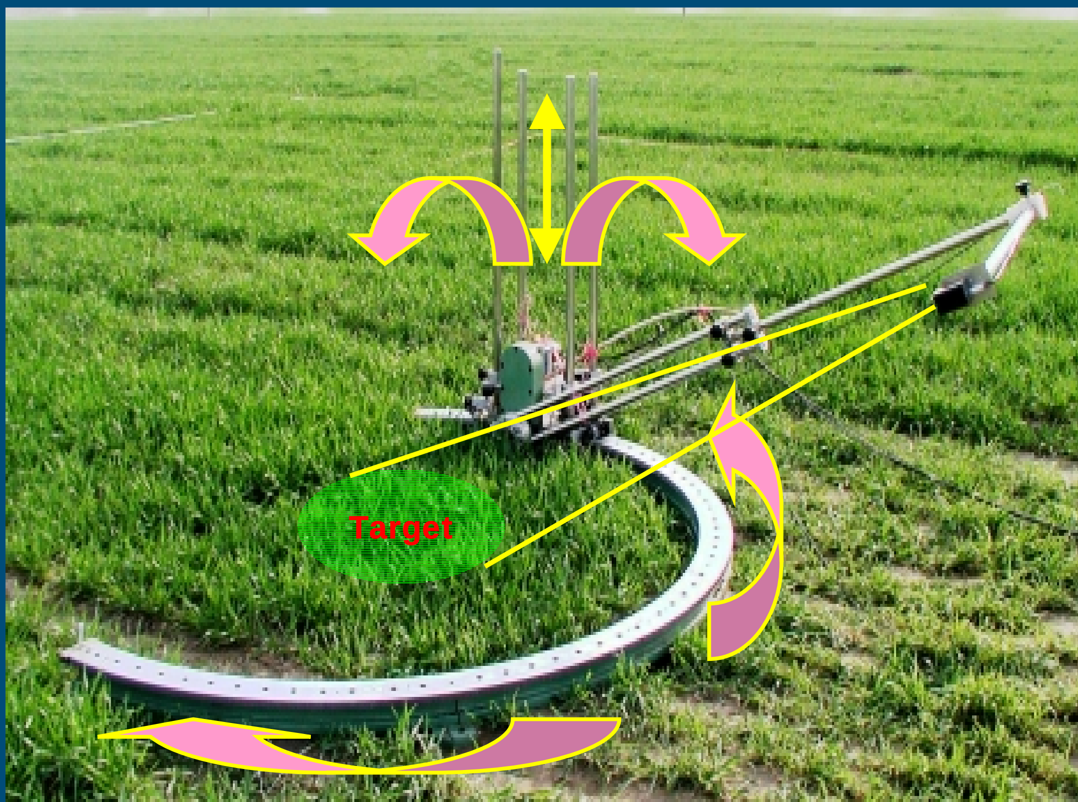
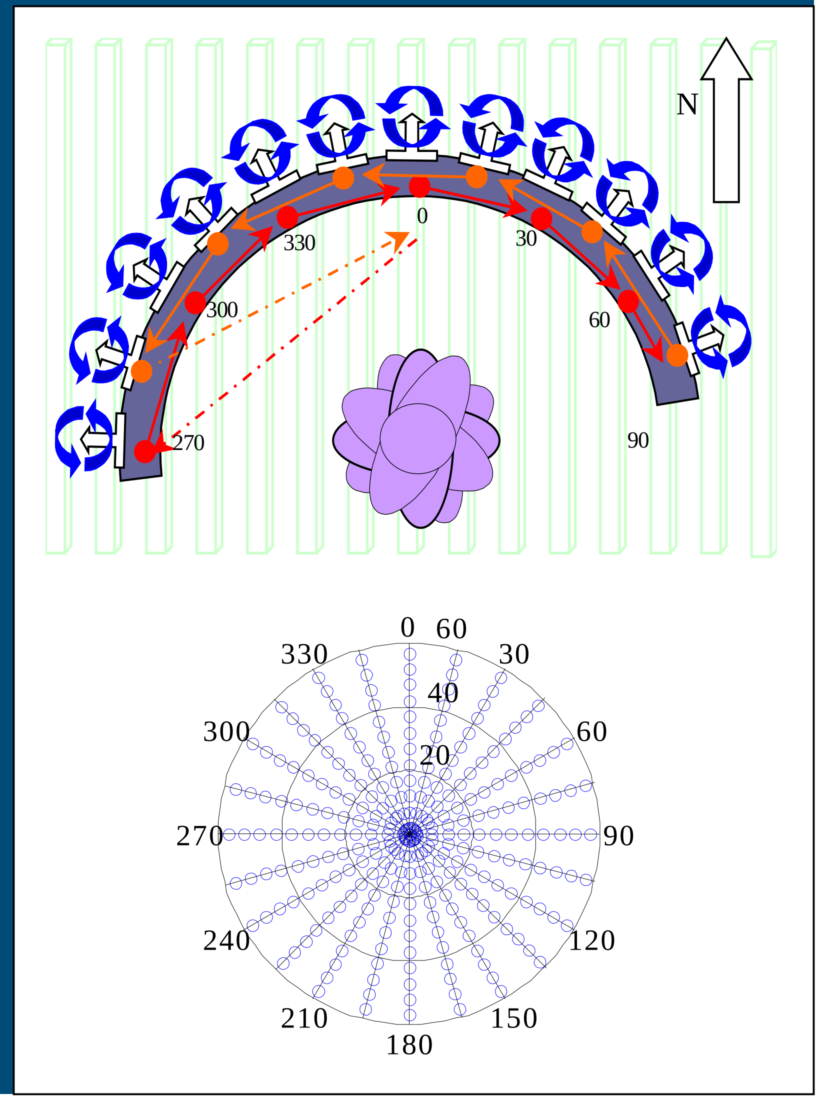
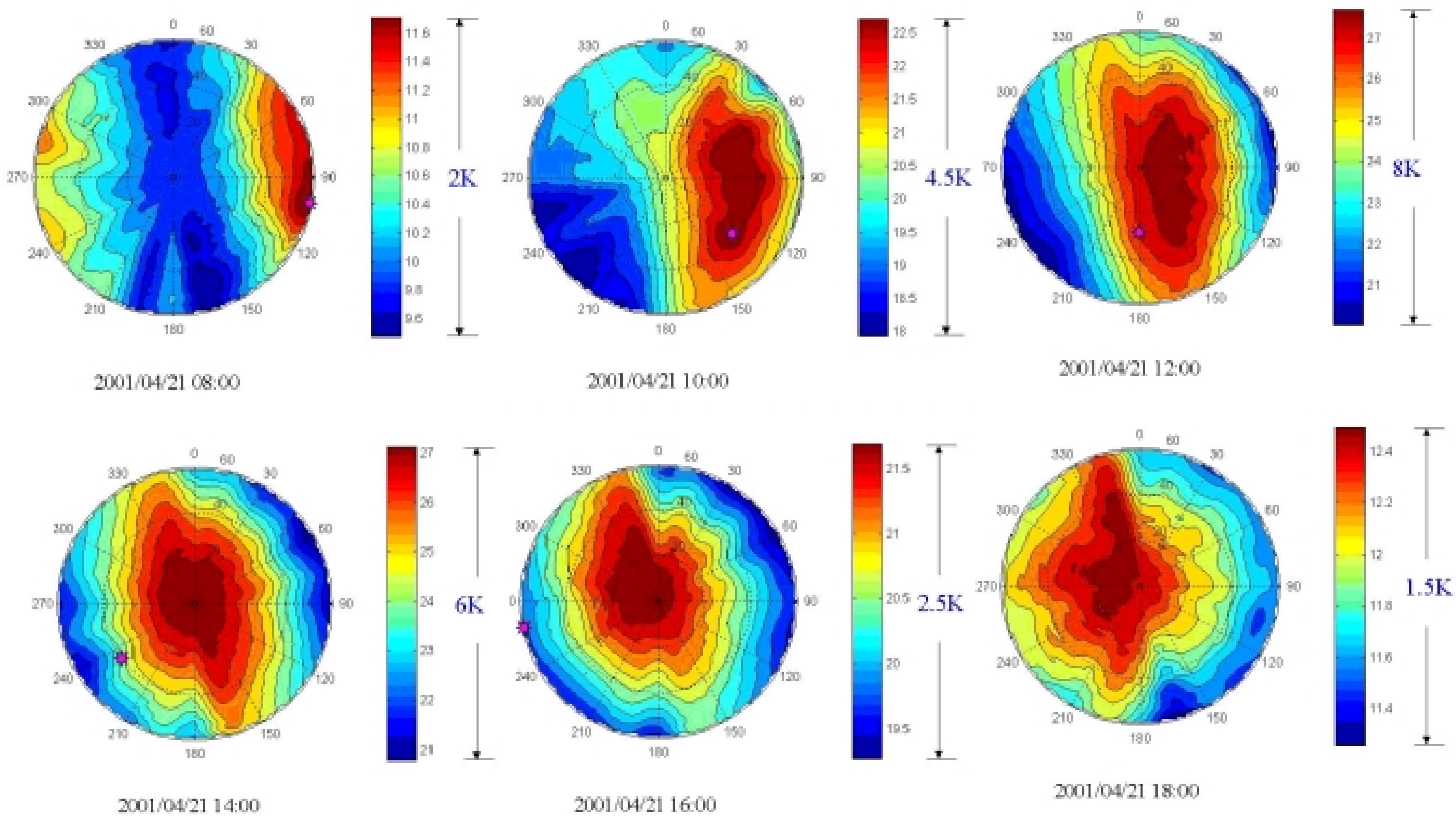
Experiment setup : goniometer measurements of directional brightness temperature

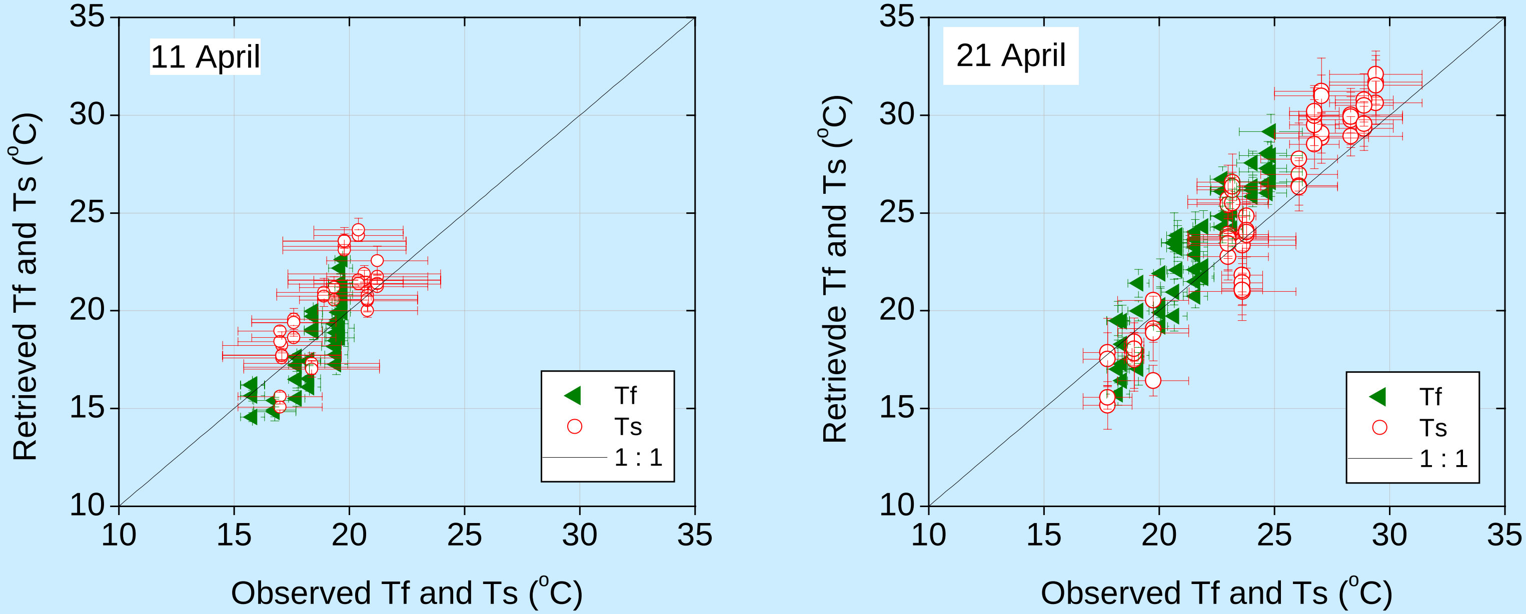




Patterns of directional brightness temperature at different solar zenith angles



Results : retrieved soil and vegetation temperatures vs. field measurements



RMSE

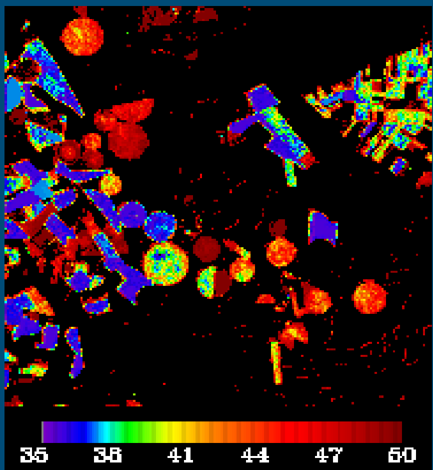
	11 April	21 April
Tf	**1.1 °C**	**1.7 °C**
Ts	**1.4 °C**	**1.7 °C**

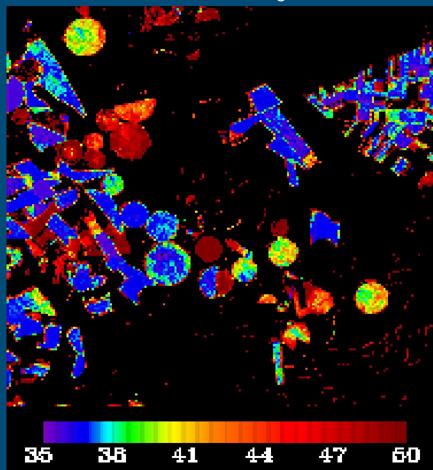
Results : retrieval of soil and foliage temperature using simulated images of TOC brightness temperature

Tb_0 at nadir

SVAT+RT model

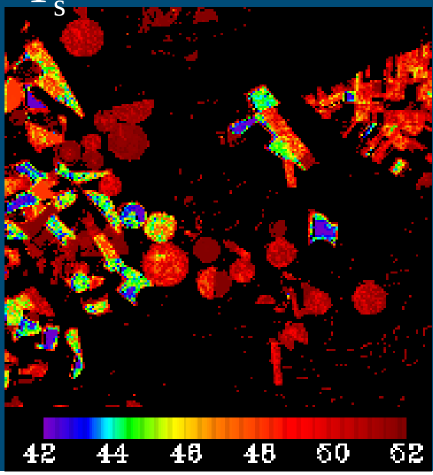
Tb_0 at 53°



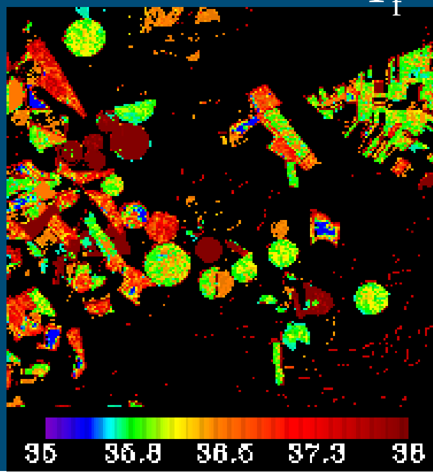


Inversion of linear model

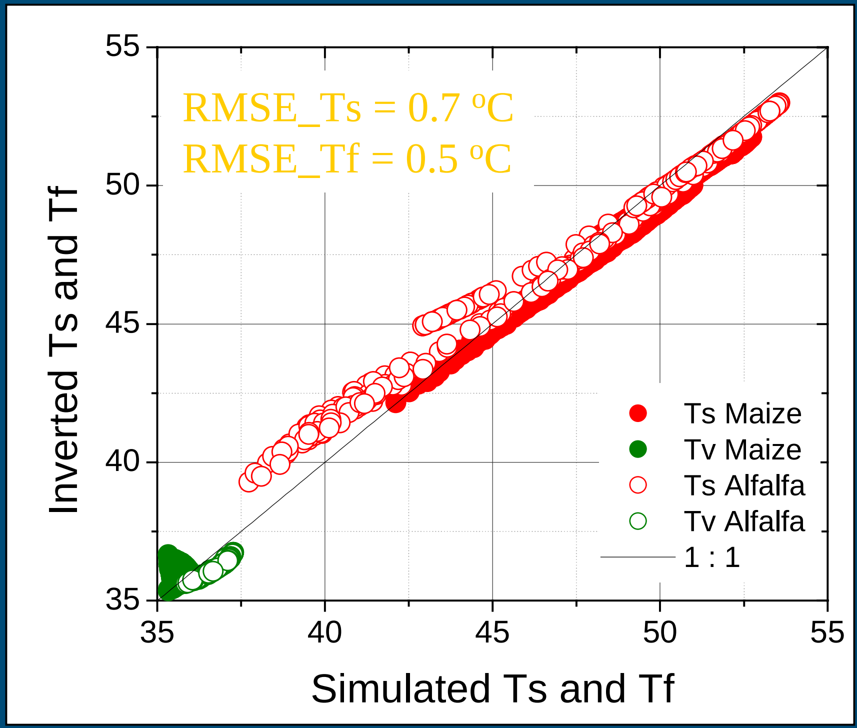
T_s



T_f



Comparison of simple linear model inversion with detailed SVAT+RT model



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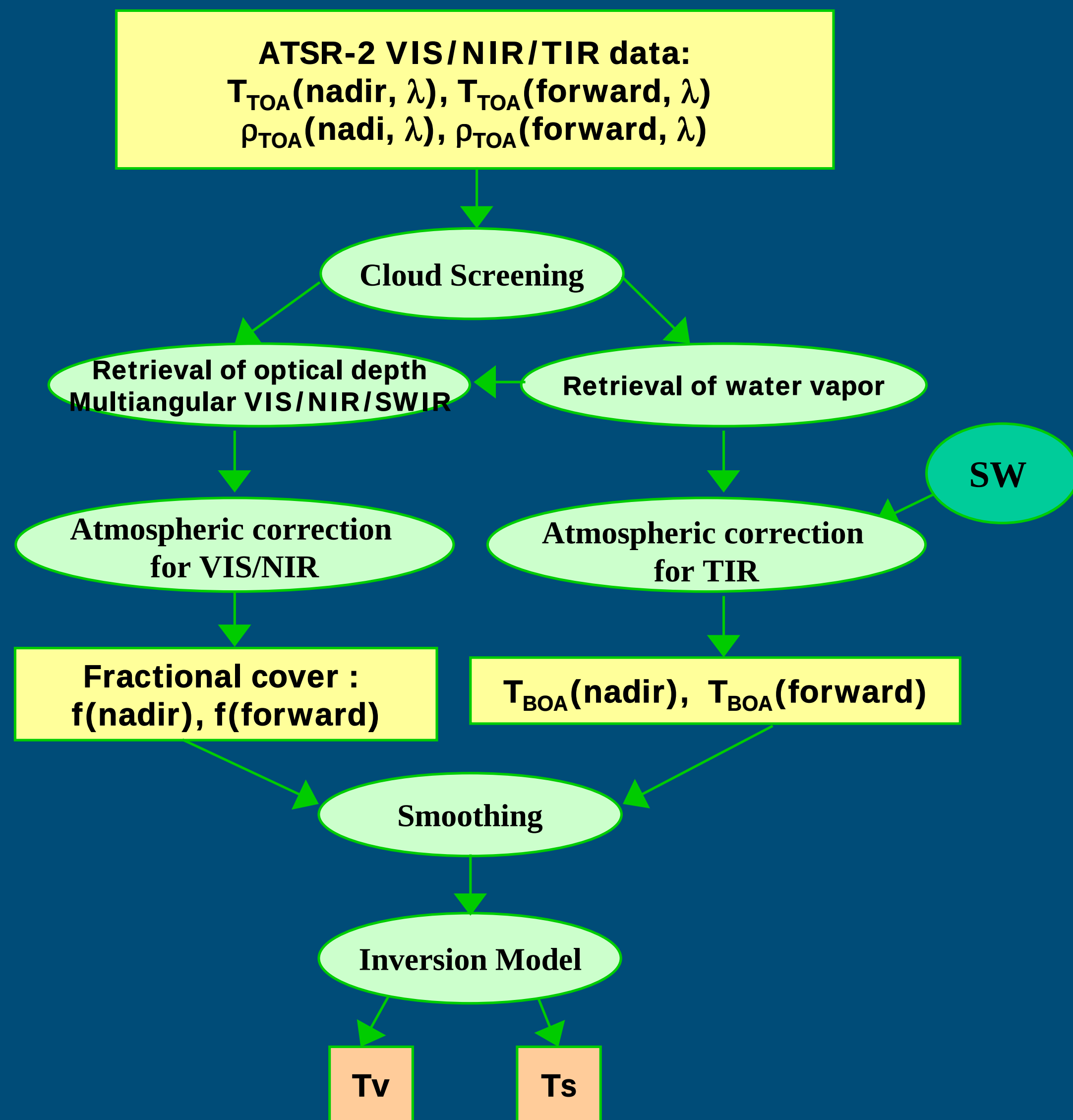
Retrieval procedures using ATSR data

ATSR-2 observations at nadir and forward view angles in VIS/NIR/TIR channels

ATSR-2 channels' information

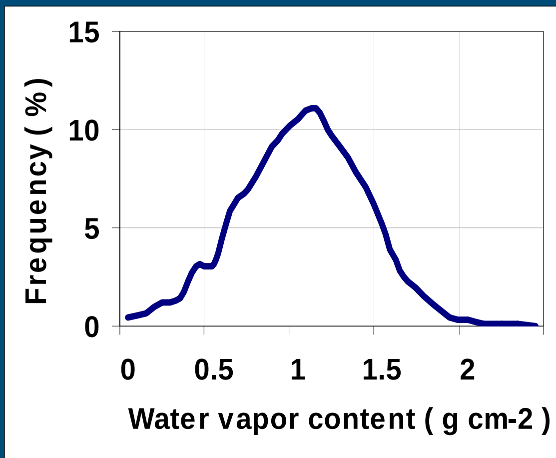
Channel	Central wavelength (µm)	50% band width (µm)
1	12.0	11.60-12.50
2	11.0	10.52-11.33
3	3.7	3.47-3.90
4	1.6	1.575-1.642
5	0.87	0.853-0.875
6	0.65	0.647-0.669
7	0.55	0.543-0.565

Spatial resolution: 1km x 1km at nadir
1.5km x 2km at forward 53 degrees

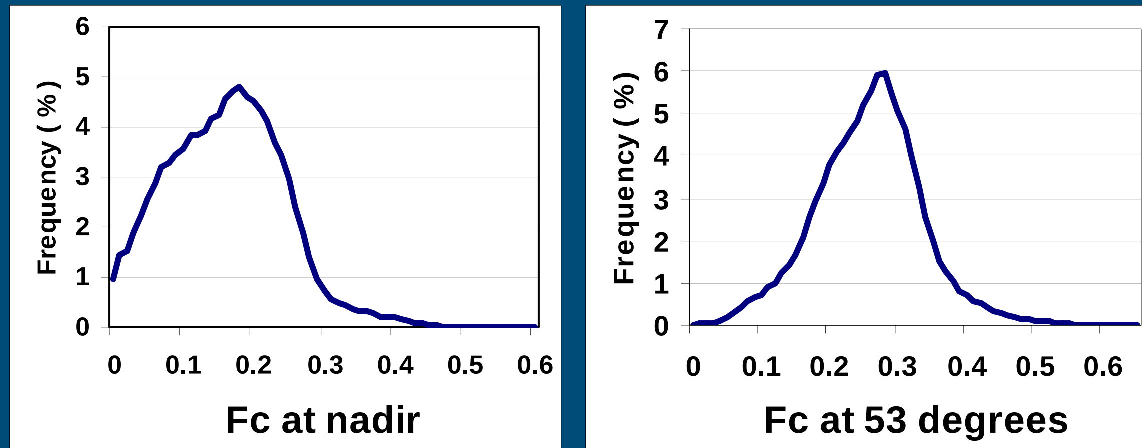


Retrieved atmospheric and surface variables

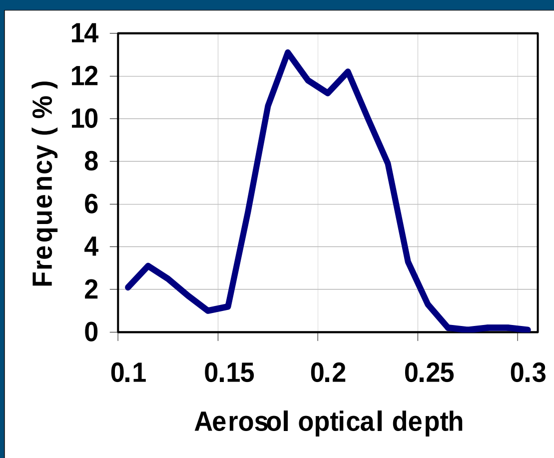
Water vapor content



Fractional vegetation cover

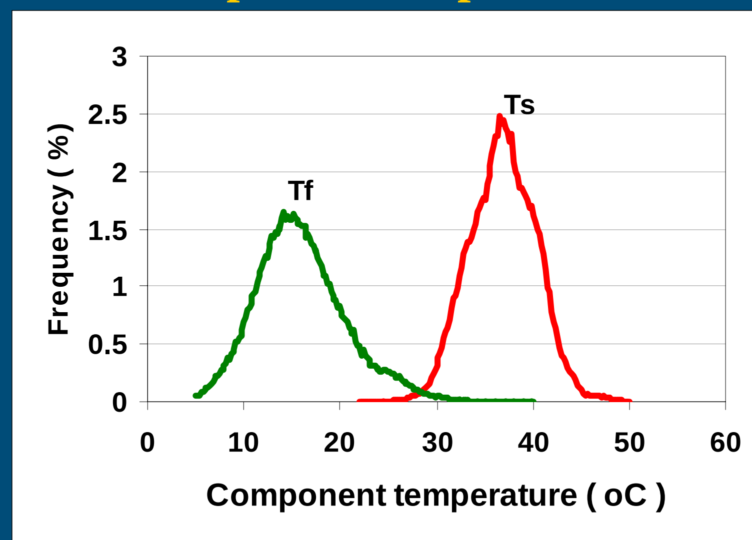


Aerosol optical depth



Spain
13 April, 1999

Component temperatures



Concluding Remarks

- A simple linear mixture model can be used to interpret directional measurements of exitance over land surface
- Ground measurements and synthetic images of TOC Tb give similar good accuracy of retrieval of Tf and Ts
- Multi-spectral and multi-angular measurements of TOA radiance by ATSR-2 allowed simultaneous retrieval of aerosol optical depth, water vapor content of atmosphere, fractional vegetation cover and soil/foliage temperatures

Acknowledgement

This work was partly supported by the project EAGLE funded by EU (EU FP6-2002-SPACE-1).