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Summer Colloquium on the Physics of Weather and Climate

Workshop on
Land-Atmosphere Interactions in Climate Models

(28 May - 8 June 2001)

Land-surface Modeling of Intermediate Complexity for NWP and Climate: the ECMWF Experience

Lecture I

Pedro Viterbo
European Centre for Medium-Range Weather Forecasts
Shinfield Park, Reading RG2 9AX
United Kingdom

These are preliminary lecture notes, intended only for distribution to participants

Land-surface modelling of intermediate complexity for NWP and climate: the ECMWF experience

Pedro Viterbo

European Centre for Medium-Range Weather Forecasts

viterbo@ecmwf.int

ECMWF
Shinfield Park
Reading
RG2 9AX
UK

ICTP, May 2001

Layout

- <u>Introduction</u>
- <u>General remarks</u>
- <u>Model development and validation</u>
- The surface energy budget
- Soil heat transfer
- Soil water transfer
- Surface fluxes
- Initial conditions
- Snow
- Conclusions and a look ahead

Lecture 1: Introduction; General remarks; Model development and validation

Lecture 2: The surface energy budget; Soil heat transfer

Lecture 3: Soil water transfer; Surface fluxes; Initial conditions; Snow; Conclusions and a look ahead

Methodology

- Snippets of plant and soil science
- ECMWF model
- Justification and examples

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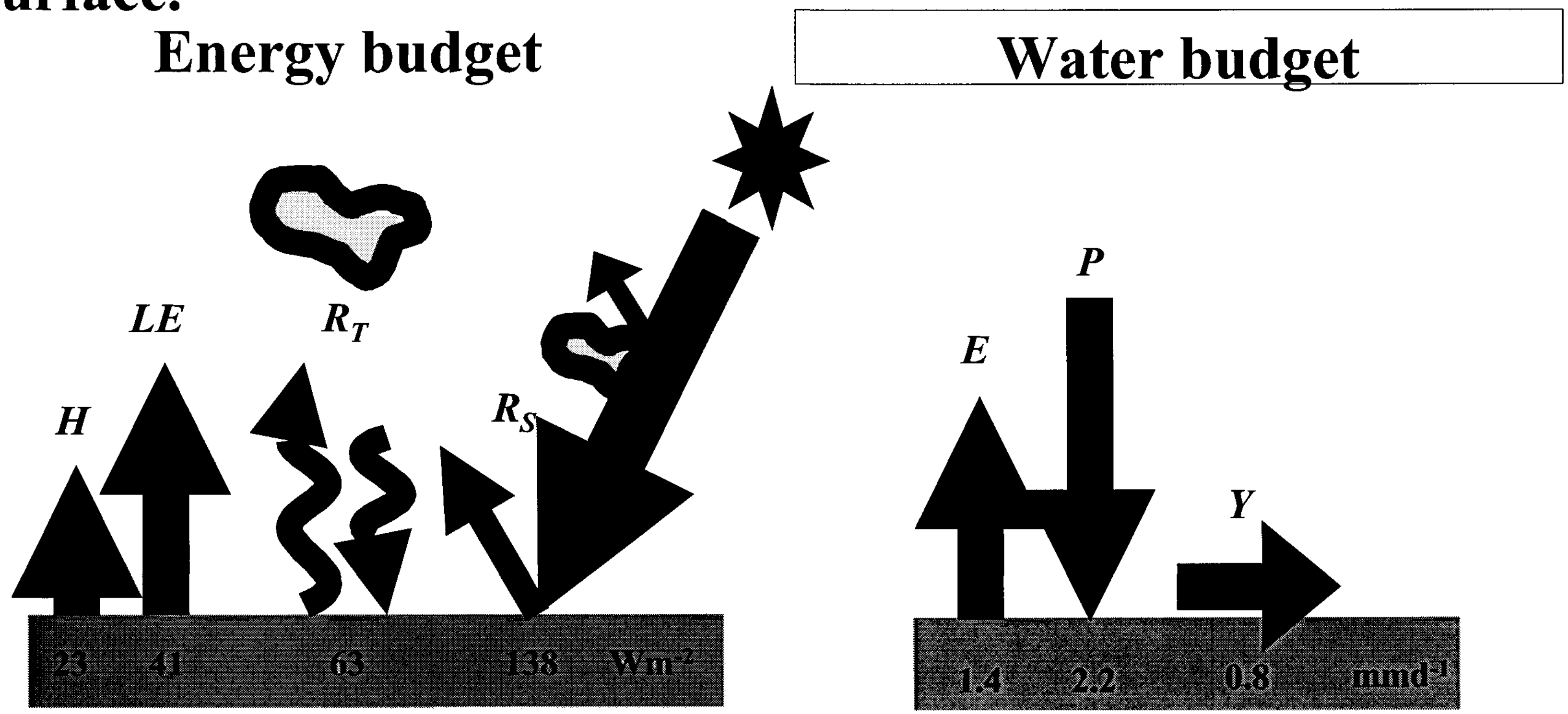
Role of land surface (1)

- Atmospheric general circulation models need boundary conditions for the enthalpy, moisture (and momentum) equations: Fluxes of energy, water (and stress) at the surface.



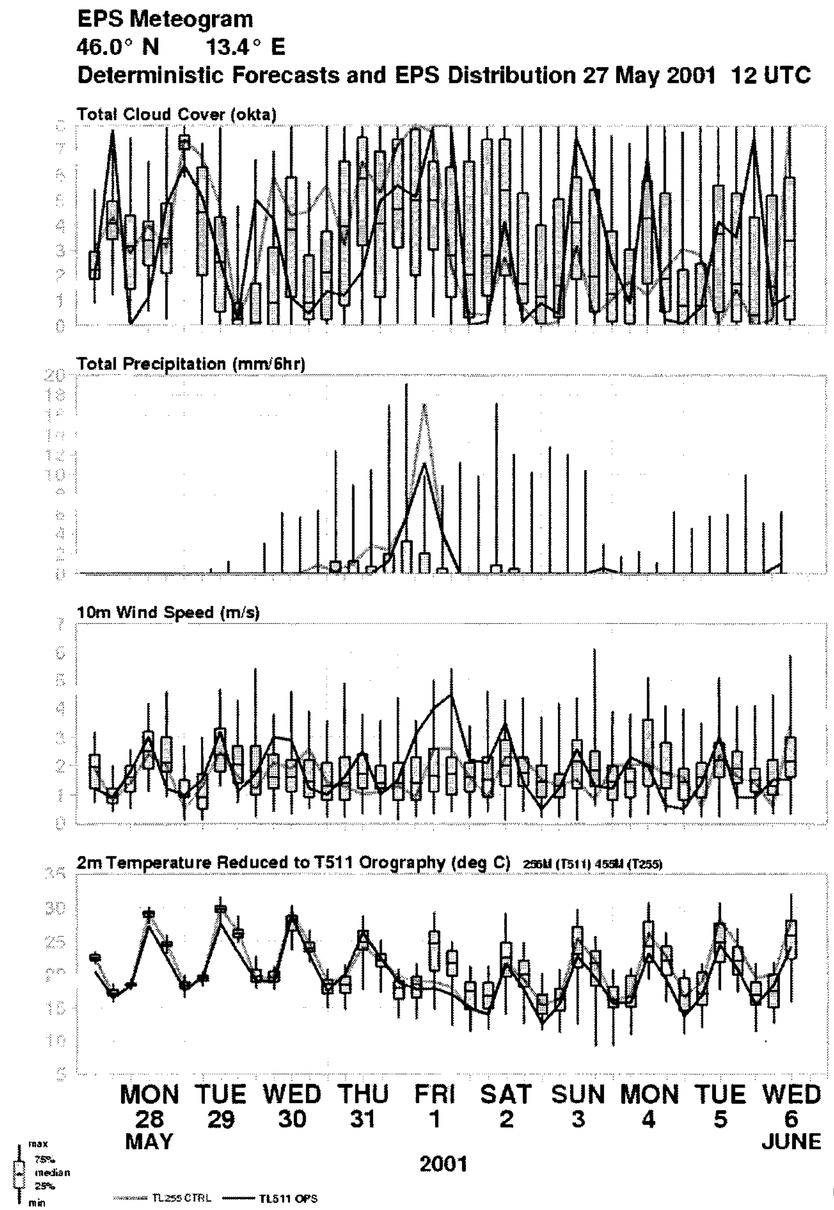
ERA15 land-averaged values 1979-1993

Role of land surface (2)

- **Numerical Weather Prediction models need to provide near surface weather parameters (temperature, dew point, wind, low level cloudiness) to their customers.**
  - **ECMWF model(s) and resolutions**

	Length	Horizontal resolution	Vertical levels	Remarks
• Deterministic	10 d	Tl511 (40 km)	L60	
• Ensemble prediction	10 d	Tl255 (80 km)	L40	(50+1 models)
• Seasonal forecast	6 m	T63 (200 km)	L31	(Ocean coupled)
• Assimilation physics	12 h	T159 (115 km)	L60	

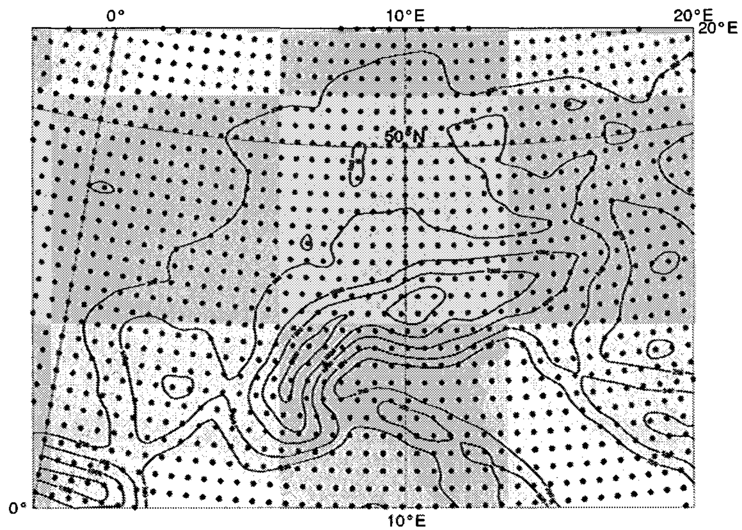
Forecast for Trieste



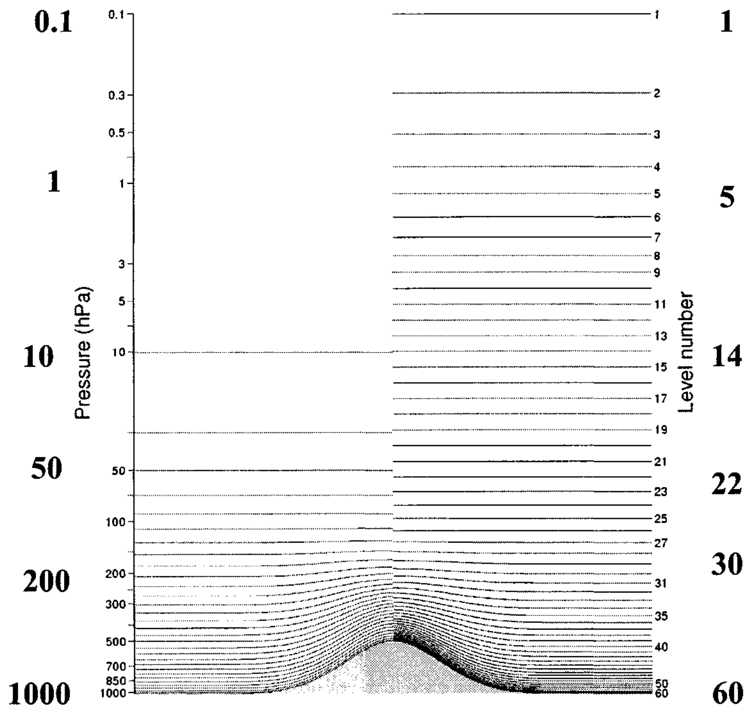
ECMWF deterministic model

- **10 day forecasts**

Horizontal resolution
Tl511 ~ 40 km



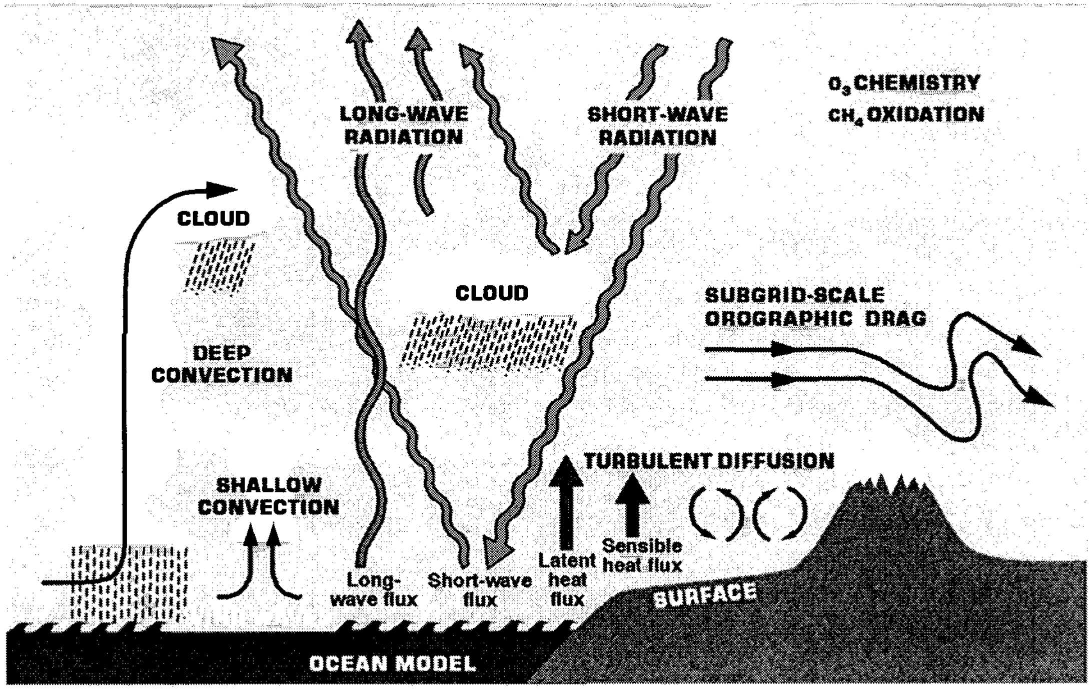
Vertical resolution
60 levels



12 levels below 850 hPa

Role of land surface (3)

- **Feedback mechanisms for the other physical processes, e.g.:**
  - **Surface evaporative fraction[1] (*EF*), impacting on low level cloudiness, impacting on surface radiation, impacting on …**
  - **Bowen ratio[2] (*Bo*), impacting on cloud base, impacting on intensity of convection, impacting on soil water, impacting on …**



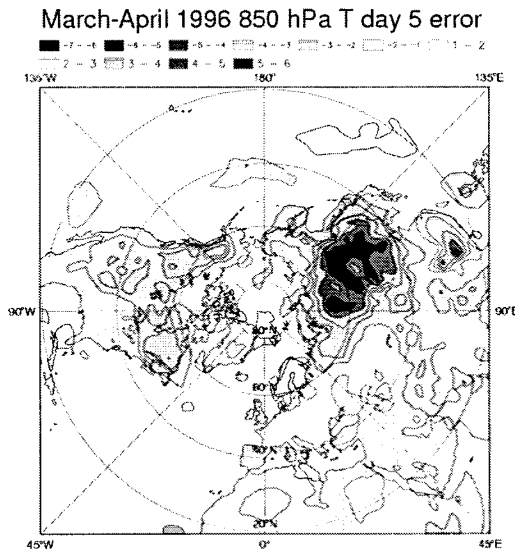
(1) *EF* = (Latent heat)/(Net radiation) **(2) *Bo* = (Sensible heat)/(Latent heat)**

Role of land surface (4)

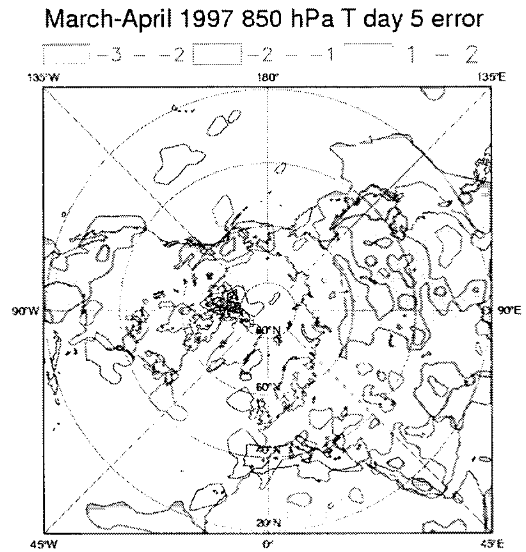
- **Partitioning between sensible heat and latent heat determines soil wetness, acting as one of the forcings of low frequency variability (e.g. extended drought periods).**
- **At higher latitudes, soil water only becomes available for evaporation after the ground melts. The soil thermal balance and the timing of snow melt (snow insulates the ground) also controls the seasonal cycle of evaporation.**
- **The outgoing surface fluxes depend on the albedo, which in turn depends on snow cover, vegetation type and season.**
- **Surface (skin) temperatures of sufficient accuracy to be used in the assimilation of TOVS satellite radiances (over land there is no measured input field analogous to the sea surface temperature)**

Systematic errors 850 hPa T

1996 operational bias



1997 operational bias



Viterbo and Betts, 1999

- **A smaller albedo of snow in the boreal forests (1997) reduces dramatically the spring (March-April) error in day 5 temperature at 850 hPa**

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Global budgets (1)

- **Mean surface energy fluxes (Wm^{-2}) in the ERA15 atmospheric reanalysis (1979-1993); positive fluxes downward**

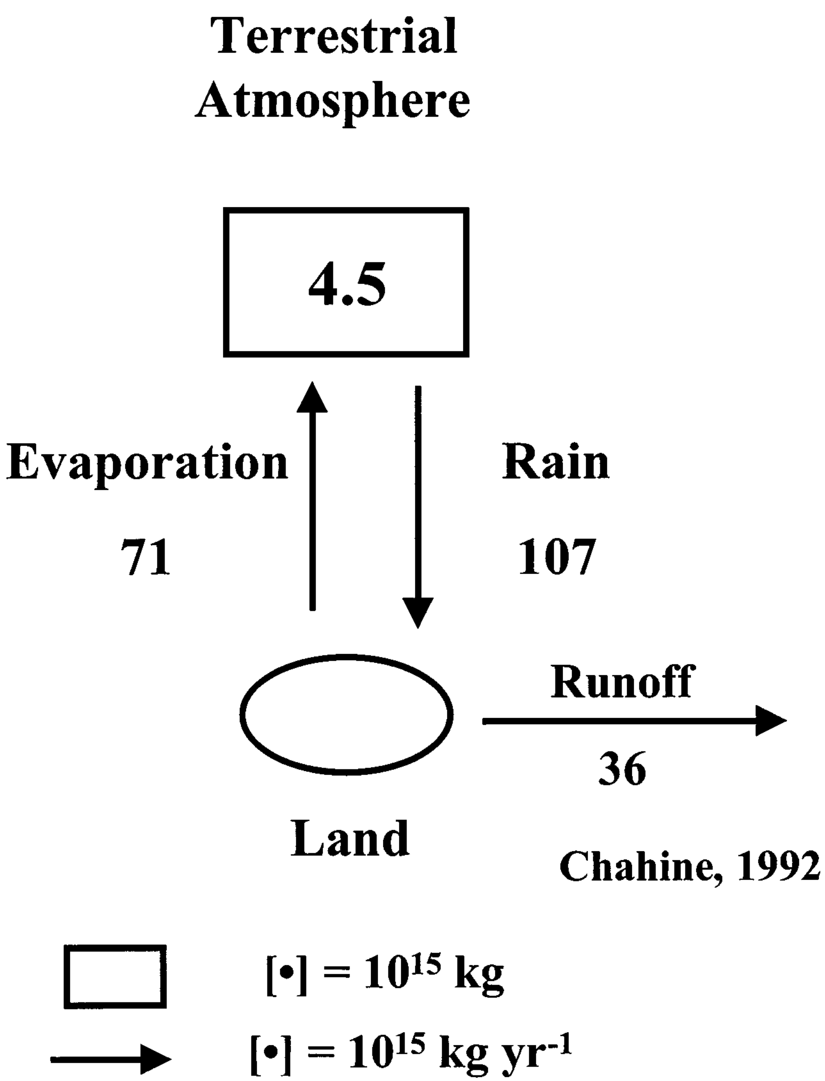
	R_S	R_T	H	LE	G	$Bo=H/LE$
Land	138	-63	-23	-41	0	0.6
Sea	163	-51	-10	-104	-2	0.1

- **Land surface**
  - **The net radiative flux at the surface (R_S+R_T) is downward. Small storage at the surface (G) implies upward sensible and latent heat fluxes.**
- **Bowen ratio: Land vs Sea**
  - **Different physical mechanisms controlling the exchanges at the surface**
    - **Continents: Fast responsive surface; Surface temperature adjusts quickly to maintain zero ground heat flux**
    - **Oceans: Large thermal inertia; Small variations of surface temperature allowing imbalances on a much longer time scale**

Global budgets (2)

- **Surface fluxes and the atmosphere**
  - **Sensible heat (*H*) at the bottom means energy immediately available close to the surface**
  - **Latent heat (*LE*) means delayed availability through condensation processes, for the whole tropospheric column**
  - **The net radiative cooling of the whole atmosphere is balanced by condensation and the sensible heat flux at the surface. Land surface processes affect directly (*H*) or indirectly (condensation, radiative cooling, …) this balance.**

Terrestrial atmosphere time scales



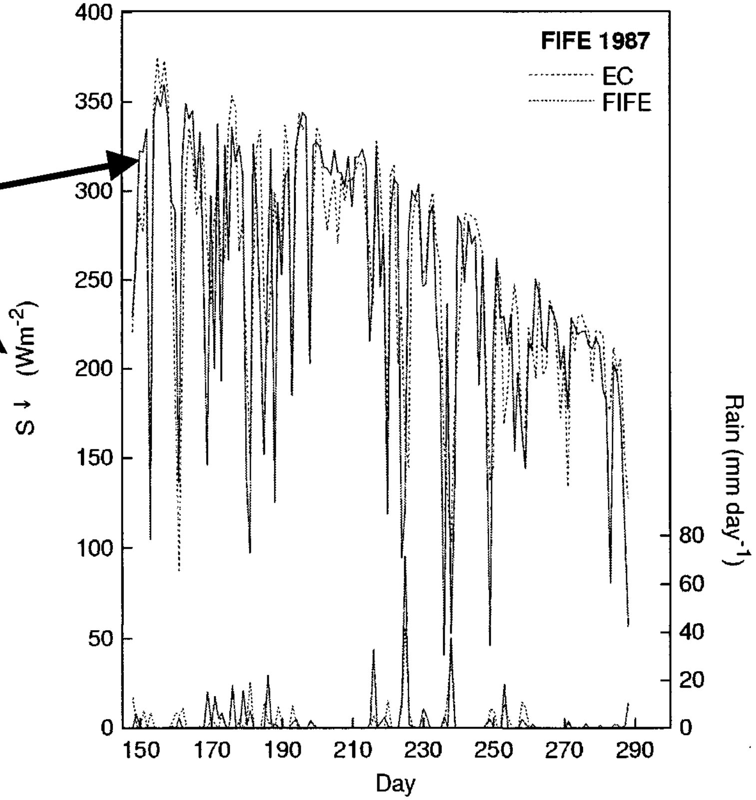
- **Atmosphere recycling time scales associated with land reservoir**

  - **Precipitation** **4.5/107 = 15 days**
  - **Evaporation** **4.5/71 = 23 days**

Surface time scales (memory) (1)

- **Diurnal time scale**
  - Forcing time scale determined by the quasi-sinusoidal radiation modulated by clouds

Downward solar radiation

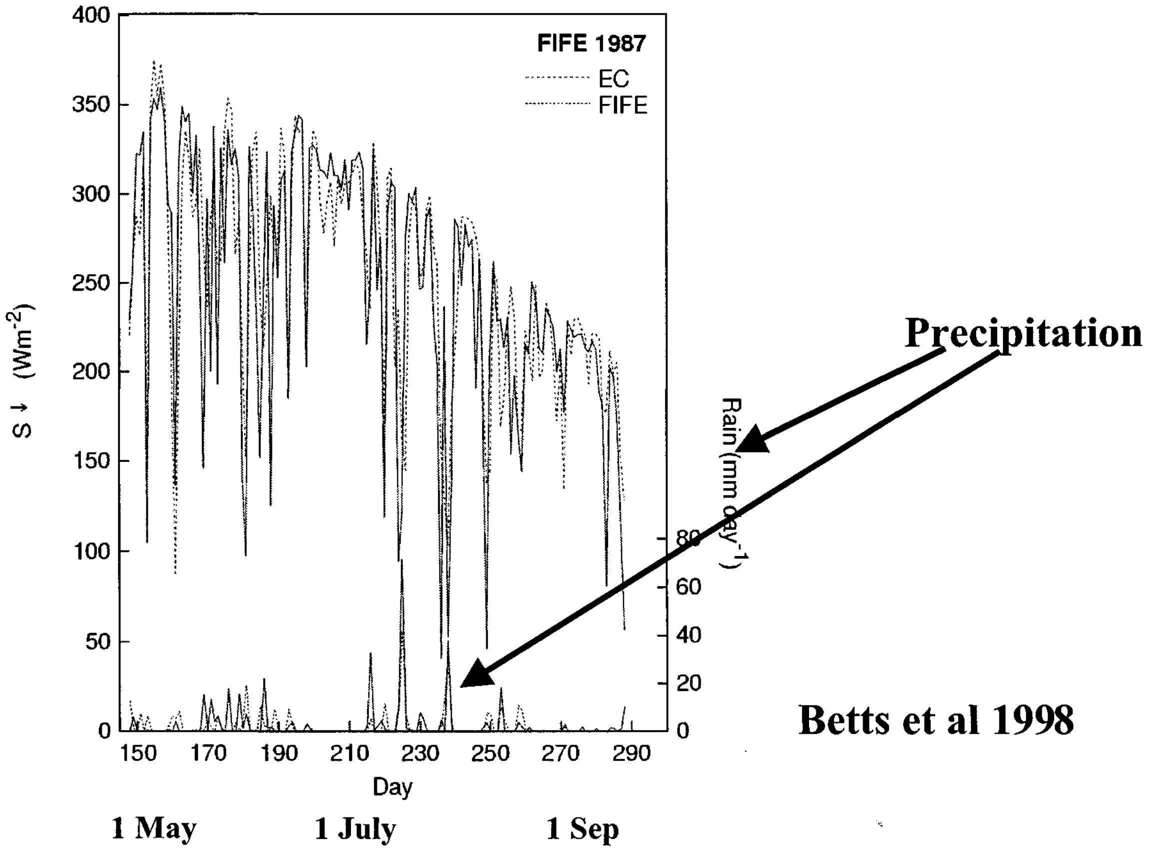


1 May 1 July 1 Sep

Betts et al 1998

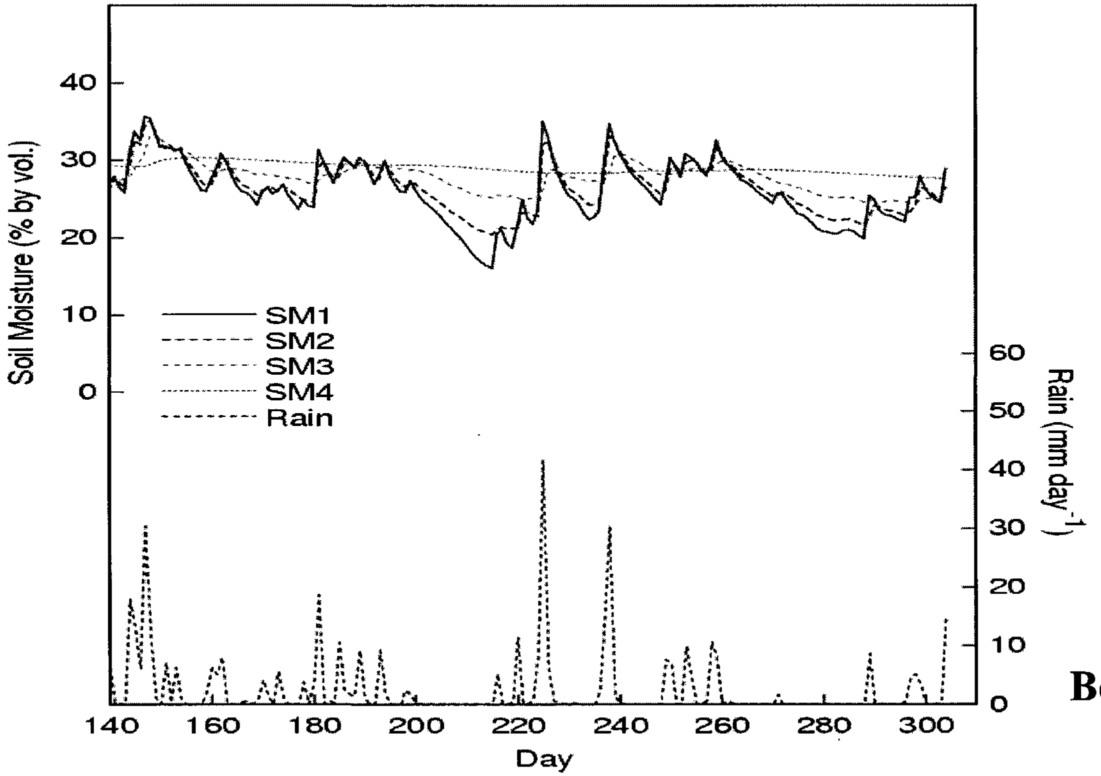
Surface time scales (memory) (2)

- **Diurnal/weekly time scale**
  - Forcing time scale determined by the "quasi-random" precipitation (synoptic/mesoscale)



Surface time scales (memory) (3)

- **Weekly/monthly time scale**
  - Internal time scale determined by the physics of soil water exchanges/transfer



Betts et al 1998

Surface time scales (memory) (4)

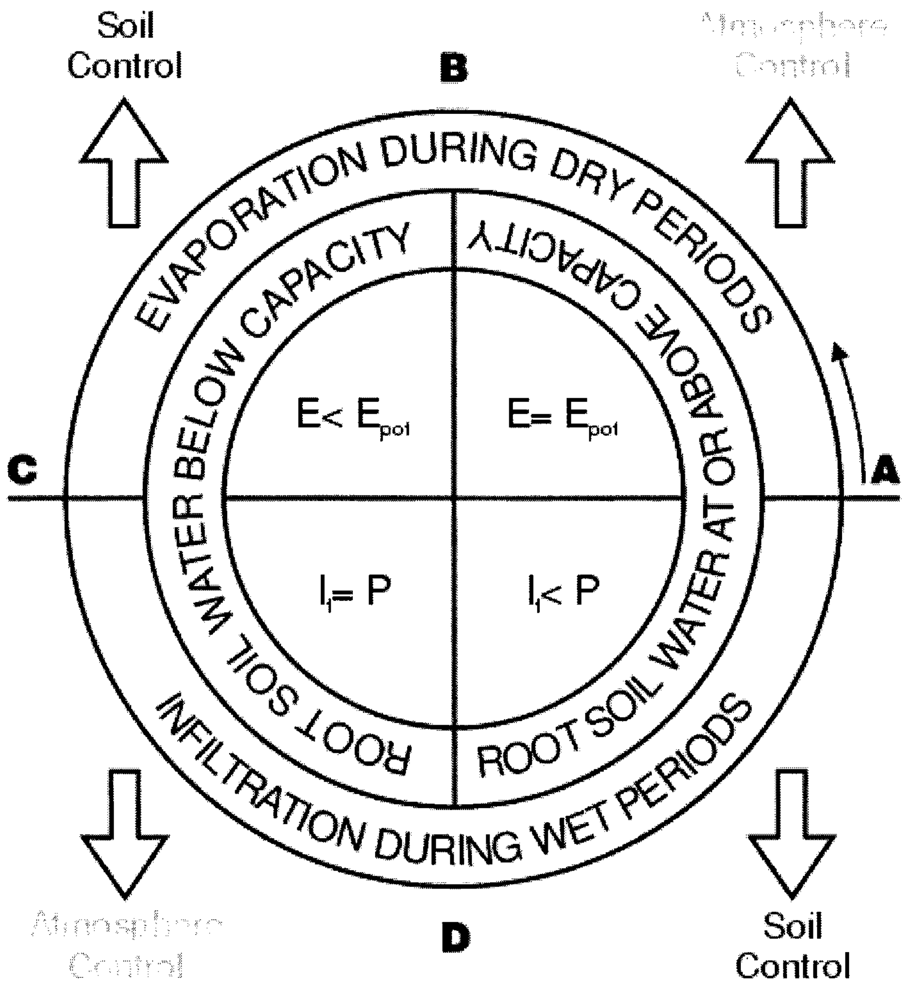
- **Weekly/monthly time scale**
  - **Evaporation time scale determined by the ratio (net radiative forcing)/(available soil water)**

R_n=150 Wm^{-2} ~ (5 $mm d^{-1}$)

Soil water=150 mm

(5 $mm d^{-1}$)/(150 mm) = 30 days

The hydrological rosette



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A diversity of models !!!

Key Model	Number Canopy Layers	Inter-ception Treated	Number of Layers Included for T	È	Roots	Canopy	Rationale for Temperature	Rationale for Soil moisture	Reference
A BATS1E	1	yes	2	3	2	Penman/Monteith	force-restore	Darcy's Law	Dickinson *et al* (1986, 1993)
B BEST	1	yes	3	2	2	Penman/Monteith	force-restore	Philip-de Vries	Pitman *et al* (1991) Cogley *et al* (1990)
C BUCKET	0	no	0	1	1	-	instantaneous surface heat balance	bucket + variation	Robock *et al* (1995)
D CLASS	1	yes	3	3	3	Penman/Monteith	heat diffusion	Darcy's Law	Verseghy (1991) Verseghy *et al* (1993)
E CSIRO	1	yes	3	2	1	aerodynamic	heat diffusion	force-restore	Kowalczyk *et al* (1991)
F GISS	1	yes	6	6	6	aerodynamic	aerodynamic	Darcy's Law	Abramopoulos *et al* (1988)
G ISBA	1	yes	2-3	2	1	aerodynamic	force-restore	force-restore	Noilhan and Planton (1989)
H TOPLATS	1	yes	1	2	1	Penman/Monteith	heat diffusion	Philip-de Vries	Famiglietti and Wood (1995)
I LEAF	1	yes	7	7	3	Penman/Monteith	heat diffusion	Darcy's Law	Avissar and Pielke (1989)
J LSX	2	yes	6	6	6	Penman/Monteith	heat diffusion	Philip-de Vries	-
K MAN69	0	no	1	1	1	-	-	bucket	Manabe (1969)
L MILLY	0	no	1	1	1	-	-	bucket	Manabe (1969)
M MIT	0	no	3	3	3	-	heat diffusion	Darcy's Law	Abramopoulos *et al* (1988) Entekhabi and Eagleson (1989)
N MOSAIC	1	yes	2	3	2	Penman/Monteith	-	Darcy's Law	Koster and Suarez (1992a)
O NMC-MRF	1	yes	1	1	1	lumped with soil	-	-	Pan (1990)
P CAPS	1	yes	2	2	1	Penman/Monteith	heat diffusion	diffusion	Mahrt and Pan (1984)
Q PLACE	1	yes	30	30	2	Ohm's law analogy	force-restore	force-restore	Wetzel and Chang (1988)
R RSTOM	-	no	0	1	1	-	-	bucket + variation	Milly (1992)
S SECHIBA	1	yes	2	2	1	Penman/Monteith	force-restore	Choisnel	Ducoudré *et al* (1993)
T SSIB	1	yes	2	3	1	Penman/Monteith	force-restore	diffusion	Xue *et al* (1991)
U UKMO	1	yes	4	1	1	Penman/Monteith	heat diffusion	diffusion	Warrilow *et al* (1986)
V VIC	1	yes	1	2	1	Penman/Monteith or full energy balance	heat diffusion	Philip-de Vries	Liang *et al* (1994)
W BIOME	1	yes	1	1	1	Penman/Monteith	force-restore	-	

Table 3.1 *Characteristics of several land surface parametrization schemes*

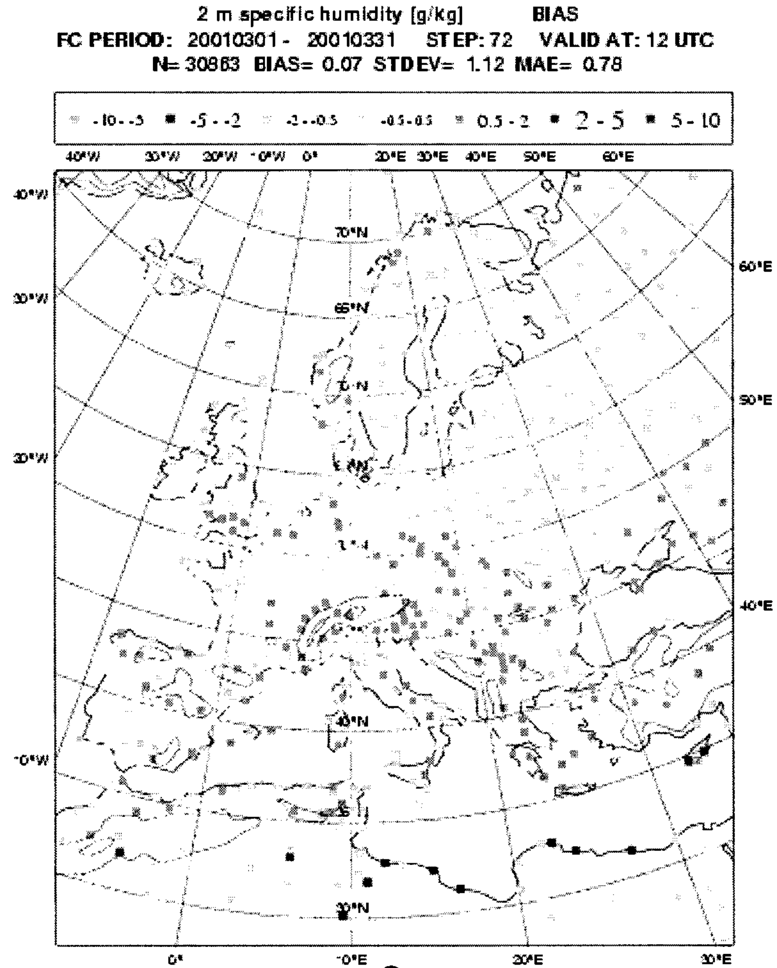
Pitman et al 1993, with modifications

Model development methodology (1)

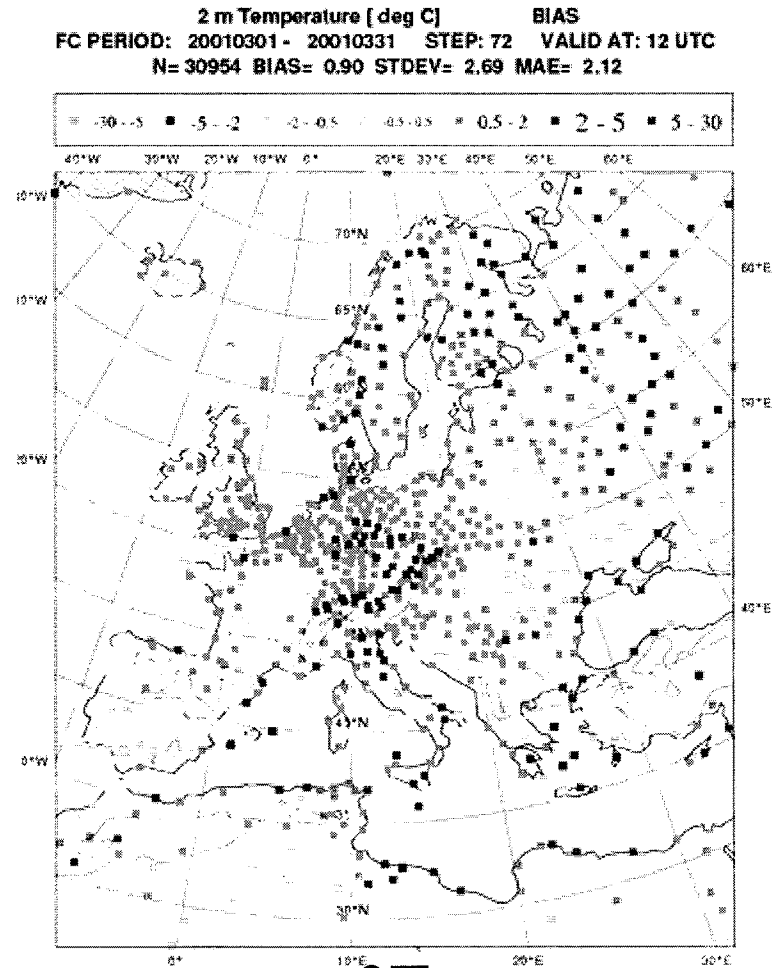
- **Operational model results vs. observations**
  - screen level T,q, low level cloudiness of 3D runs

Europe FC errors for March 2001

72 H FC verifying at 12 UTC



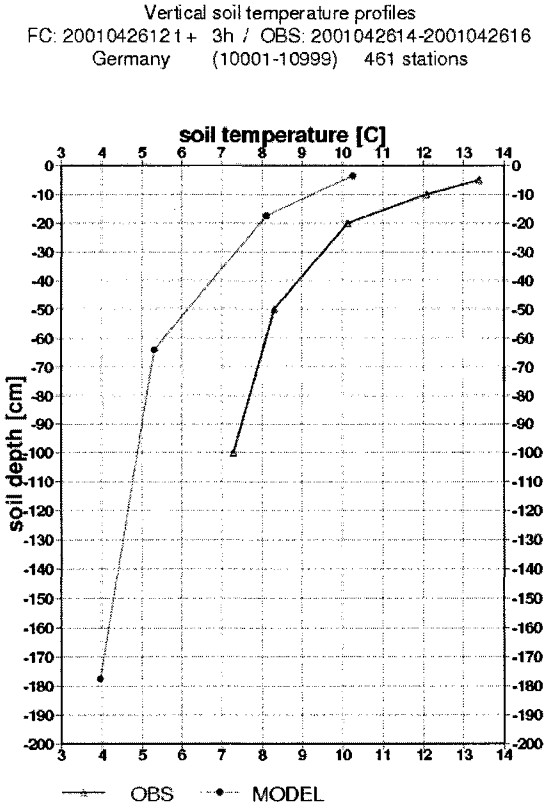
2q



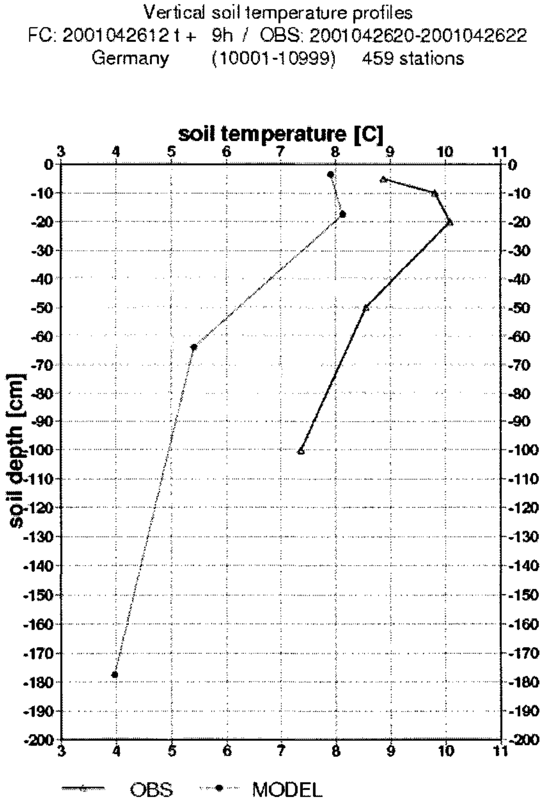
2T

Soil temperature verification

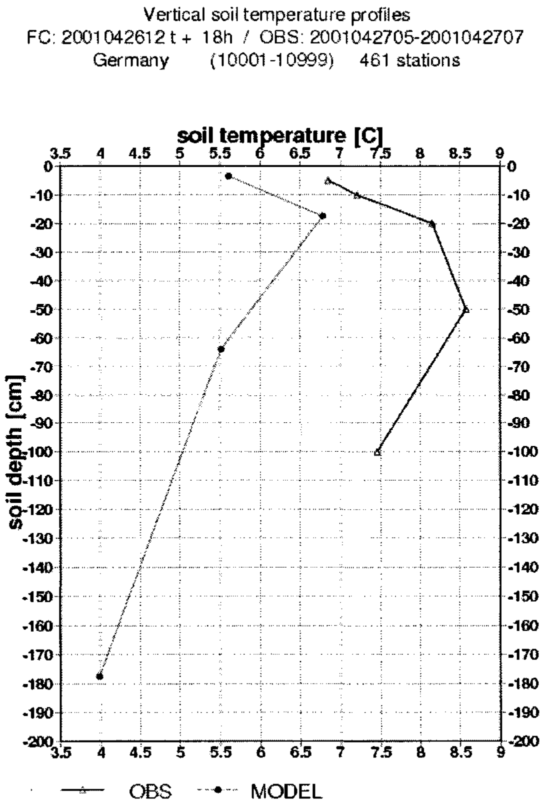
Averaged over Germany stations 26 April 2001



Verifying at 15 UTC



Verifying at 21 UTC



Verifying at 06 UTC

Model development methodology (1)

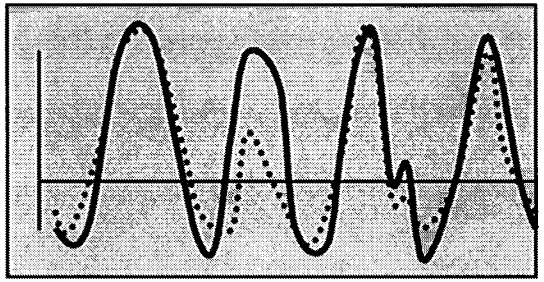
- **Operational model results vs. observations**
  - screen level T,q, low level cloudiness of 3D runs
  - Basin averaged surface hydrological budget of 3D runs
- **Identification of missing/misrepresented physical mechanisms**
- **Changing the model formulation**
- **Identification of potential validation data sets and methodology for controlled validation**
- **Testing in "controlled" mode (ie, cutting most feedbacks)**
  - 1-column 1-2 day integrations
  - Surface only integrations, 1 month to several years, forced to obs
  - 1-column integrations with data assimilation emulation, months/years
  - 3D relaxation integrations: A cheap proxy for data assimilation

Model development methodology (2)

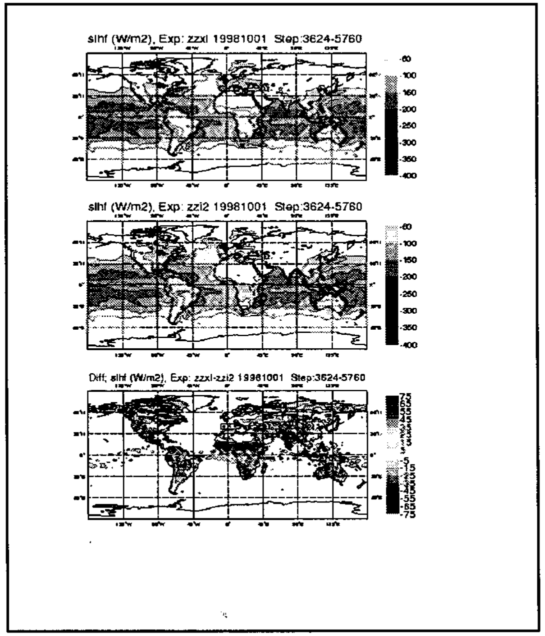
- 3D testing with model and model/assimilation
- 3D testing with idealised configurations for further identification of feedback mechanisms

Validation/evaluation of TESSEL

Evaluation of the new scheme



- offline, using 7 different datasets:
  - Cabauw 1987
  - Hapex-MOBILHY 1986
  - FIFE 1987-1989
  - BOREAS 1994-1996
  - ARME (tropical forest) 1983-1985
  - Garderen (Dutch pine forest) 1989
  - SEBEX (Sahel) 1989-1990



- in relaxation experiments (forcing upper model fields to analyses: useful for shallow boundary layers)

- in reanalysis test suite (1987-1988)

ECMWF surface model: milestones

• Vegetation based evaporation	1989
• CY48 (4 layers + …)	1993 / ERA15
• Initial conditions for soil water	1994
• Stable BL/soil water freezing	1996
• Albedo of snow forests	1996
• OI increments of soil water	1999
• TESSEL, new snow and sea ice	2000 / ERA40
• …	

ECMWF model and validation

- **Model Description**

  Viterbo and Beljaars, 1995. J. Climate, 2716-2748.

  van den Hurk et al, 2000. EC Tech Memo 295.

- **1D validation**
  - Cabauw

    Beljaars and Viterbo, 1994. BLM, 71, 135-149.

    Viterbo and Beljaars, 1995. J. Climate.
  - FIFE

    Viterbo and Beljaars, 1995. J. Climate.
    Betts et al. 1996. JGR, 101D, 7209-7225.
    Betts et al., 1998. Mon. Wea. Rev., 126, 186-198.
    Douville et al, 2000: MWR, 128, 1733-1756.
  - ARME

    Viterbo and Beljaars, 1995. J. Climate.
  - SEBEX

    Beljaars and Viterbo, 1999. Cambridge Univ Press.

    van den Hurk et al, 2000.
  - All the above + HAPEX-MOBIHLY+BOREAS

    van den Hurk et al, 2000.

- **US Summer 1993**

  Beljaars et al. 1996. MWR, 124, 362-383.
  Betts et al. 1996. JGR, 101D, 7209-7225.

  Viterbo and Betts, 1999: JGR, 104D, 19,361-19,366.

- **Soil water initial conditions**

  Viterbo, 1996.
  Douville et al, 2000.

- **Soil freezing**

  Viterbo et al., 1999. QJRMS, 125,2401-2426.

- **Snow forest albedo**

  Viterbo and Betts, 1999. JGR, 104D, 27,803-27,810.

- **Mississippi river basins**

  Betts et al., 1998. J. Climate, 11, 2881-2897.

  Betts et al., 1999. JGR, 104D,19,293-19,306.

- **Mackenzie river basin**

  Betts and Viterbo, 2000: J. Hydrometeor, 1, 47-60.

- **Impact of land on weather**

  Viterbo and Beljaars, 2001: Springer, to appear.

Modelling the real world

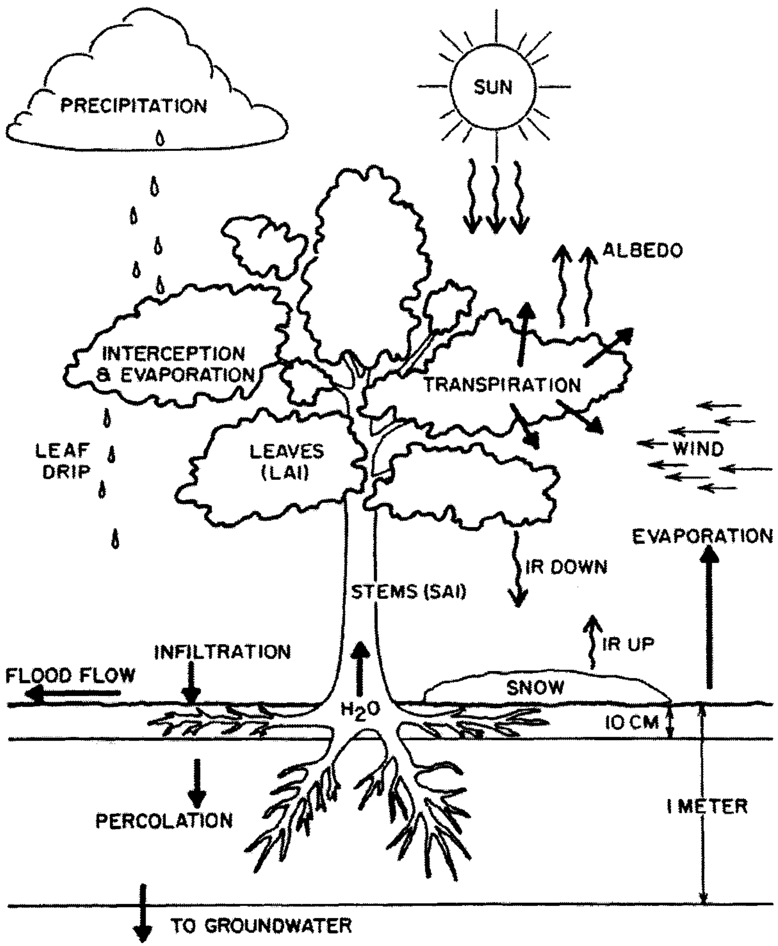


Figure 7
Water and energy processes at the Earth surface in the presence of vegetation.

Verstraete and Dickinson 1986

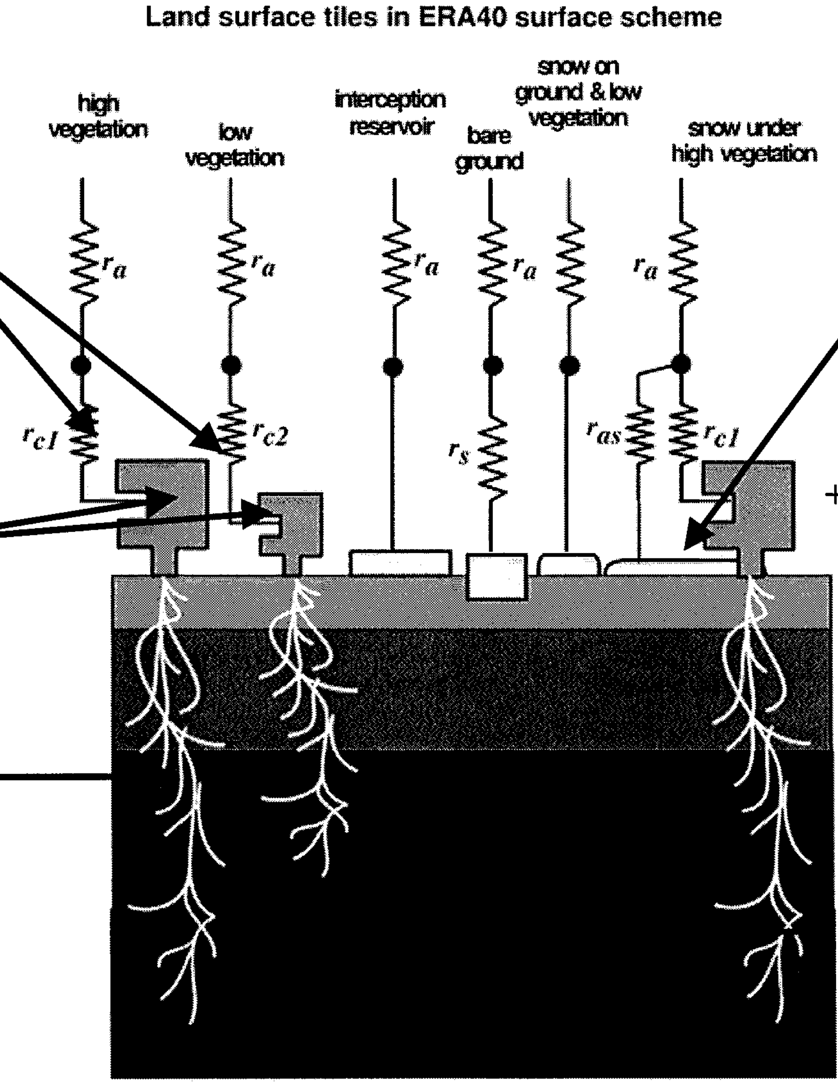
TESSEL scheme in a nutshell

- **Tiled ECMWF Scheme for Surface Exchanges over Land**

Revised canopy resistances, including air humidity stress on forest

High and low vegetation treated separately

Variable root depth



New treatment of snow under high vegetation

+ 2 tiles (ocean & sea-ice)

No root extraction or deep percolation in frozen soils