Consistent interfacing of surface schemes

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- discussion

Best, Beljaars, Polcher, Viterbo, 2004

- Externalisation would allow “the attribution of differences in the model as a whole to differences in de land surface scheme”. Different *worlds*: ALADIN-ALARO-AROME-ARPEGE, ECMWF (via IFS), HIRLAM, meso-NH, SURFEX

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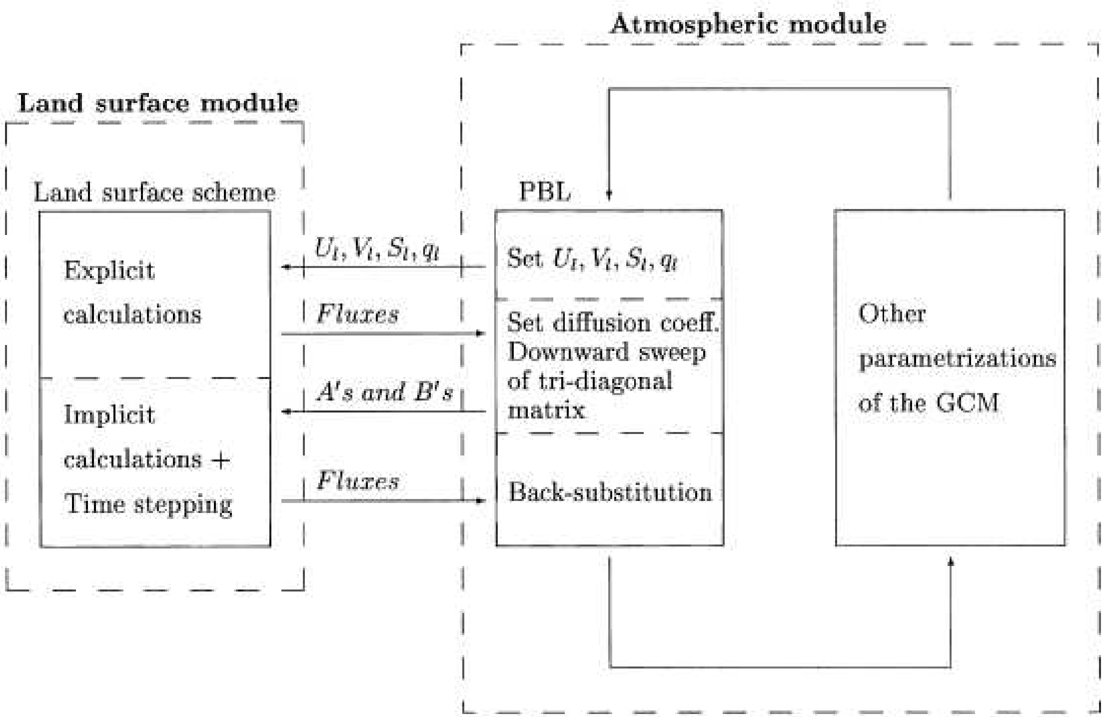
- Be my guest or be a good guest?

Best, Beljaars, Polcher, Viterbo, 2004



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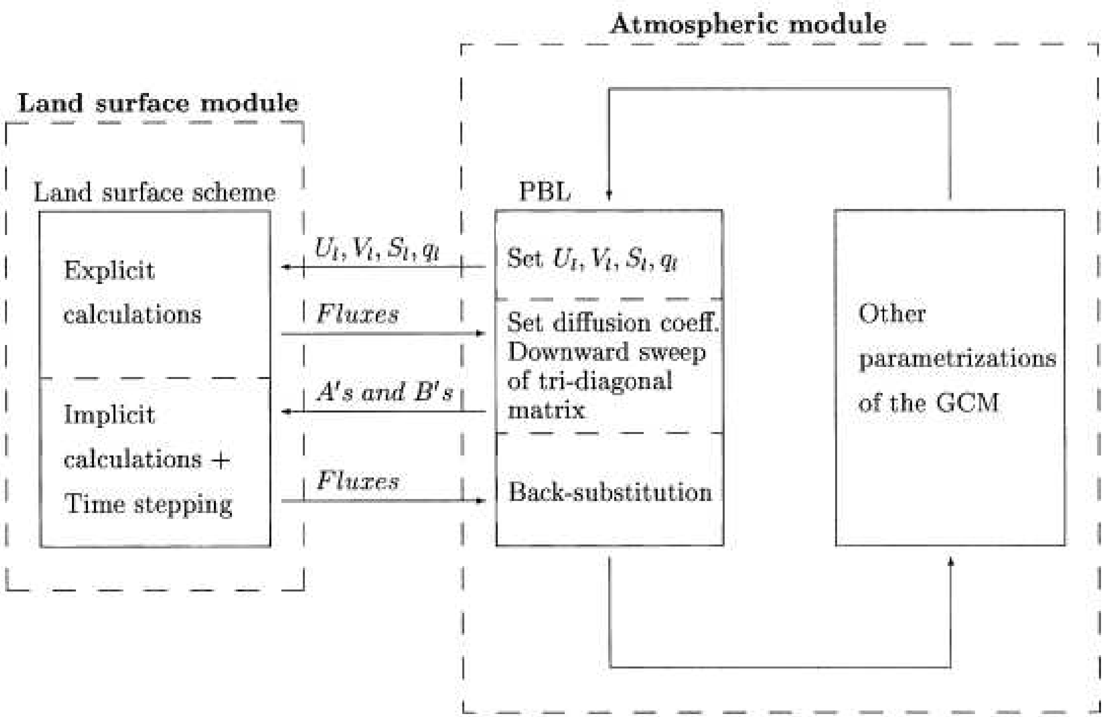

+ Enquiry mode

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TABLE 1. Variables to be passed within the coupling scheme. This table does not include the domain-describing variables such as geographical coordinates, time, or height of atmospheric levels. The surface scheme should respond with output dependent on a mode flag (enquiry mode, explicit mode, or time-stepping mode). The output variables are all tile averaged.

Input variables (from atmospheric model)	Output variables (from surface scheme)
Lowest-level east–west wind speed (m s^{-1})	Enquiry mode
Lowest-level north–south wind speed (m s^{-1})	Surface albedo (—)
Lowest-level dry static energy (J kg^{-1})	Surface emissivity (—)
Lowest-level specific humidity (kg kg^{-1})	Surface radiative temperature (K)
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Solar zenith angle (°)	East–west momentum flux (N m^{-2})
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A_s, B_s (dry static energy)	Sensible heat flux (W m^{-2})
$A_{\bar{q}}$, $B_{\bar{q}}$ (specific humidity)	Latent heat flux (W m^{-2})
A_U, B_U (east–west wind component)	Moisture flux (kg m^{-2} s^{-1})
A_V, B_V (north–south wind component)	Surface radiative temperature (K)

Fluxes (Best et al.)

$$
\begin{aligned}
J^U &= \rho\, C_M |\mathbf{V}| U_L \\
J^V &= \rho\, C_M |\mathbf{V}| V_L \\
J^S &= \rho\, C_H |\mathbf{V}|\, (S_L - S_s) \\
J^q &= \rho\, C_H |\mathbf{V}|\, (q_L - q_s)
\end{aligned}
$$

Fluxes: explicit computation

- explicit from of the fluxes

$$
\begin{aligned}
J^U &= \rho\, C_M |\mathbf{V}| U_l^- \\
J^V &= \rho\, C_M |\mathbf{V}| V_l^- \\
J^S &= \rho\, C_H |\mathbf{V}| \left(S_l^- - S_s^-\right) \\
J^q &= \rho\, C_H |\mathbf{V}| \left(q_l^- - q_s^-\right)
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J^q &= \rho\, C_H |\mathbf{V}| \left(q_l^- - q_s^-\right)
\end{aligned}
$$

- So if the atmospheric module passes U_l, V_l, S_l, q_l to the land surface module, the job is done (well at least from a conceptual point of view :-)

Fluxes: implicit computation

- implicit from of the fluxes (following Kalnay and Kanamistu 1988):

$$
\begin{aligned}
J^U &= \rho C_M |\mathbf{V}| U_l^+ \\
J^V &= \rho C_M |\mathbf{V}| V_l^+ \\
J^S &= \rho C_H |\mathbf{V}| \left(S_l^+ - S_s^+ \right) \\
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J^q &= \rho C_H |\mathbf{V}| \left(q_l^+ - q_s^+\right)
\end{aligned}
$$

- So we need $U_l^+, V_l^+, S_l^+, q_l^+$?, but ...

Vertical diffusion

- vertical diffusion:

$$\begin{aligned}
\psi_i^+ - \psi_i^- &= -g\frac{\Delta t}{\delta p_i}\left[K_i'\left(\psi_i^+ - \psi_{i+1}^+\right) - K_{i-1}'\left(\psi_{i-1}^+ - \psi_i^+\right)\right] \\
&= -\alpha_{i,i}\left(\psi_i^+ - \psi_{i+1}^+\right) + \alpha_{i,i-1}\left(\psi_{i-1}^+ - \psi_i^+\right) \\
\psi_l^+ - \psi_l^- &= -g\frac{\Delta t}{\delta p_l}\left[C_{Ml}'\left(\psi_l^+ - \psi_s^+\right) - K_{l-1}'\left(\psi_{l-1}^+ - \psi_l^+\right)\right] \\
&= -\alpha_{l,l}\left(\psi_l^+ - \psi_s^+\right) + \alpha_{l,l-1}\left(\psi_{l-1}^+ - \psi_l^+\right)
\end{aligned}$$

- with the fluxes

$$J_l^\psi \equiv C_{Ml}'\left(\psi_l^+ - \psi_s^+\right) \quad J_i^\psi \equiv K_i'\left(\psi_i^+ - \psi_{i+1}^+\right)$$

Gaussian elimination

- $$\begin{pmatrix} 1+\alpha_{11} & -\alpha_{11} & 0 & 0 & \\ -\alpha_{21} & 1+\alpha_{21}+\alpha_{22} & -\alpha_{22} & 0 & \\ 0 & -\alpha_{32} & 1+\alpha_{32}+\alpha_{33} & -\alpha_{33} & \\ & & & & \ddots \end{pmatrix} \begin{pmatrix} \psi_1^+ \\ \psi_2^+ \\ \psi_3^+ \\ \vdots \end{pmatrix} = \begin{pmatrix} \psi_1^- \\ \psi_2^- \\ \psi_3^- \\ \vdots \end{pmatrix}$$

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- convert to lower diagonal matrix which allows an upward sweep: $\psi_i^+ = a_i\, \psi_{i+1}^+ + b_i$.

Gaussian elimination

ACDIFUS ($\psi_s = 0$)

	$a_i = a_i(a_{i-1}; K'_i, K'_{i-1})$	
	$b_i = b_i(b_{i-1}; K'_i, K'_{i-1})$	
atmospheric	$\vdots$	downward sweep
	$a_l = a_l(a_{l-1}; K'_l, K'_{l-1})$	
	$b_l = b_l(b_{l-1}; K'_l, K'_{l-1})$	
	$\psi_l^+ = b_l$	
atmospheric	$\vdots$	back subsitution
	$\psi_i^+ = a_i\, \psi_{i+1}^+ + b_i$	

Gaussian elimination

interface @ $i = l$ ($\psi_s = 0$)

	$a_i = a_i(a_{i-1}; K'_i, K'_{i-1})$	
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	$a_l = a_l(a_{l-1}; K'_l, K'_{l-1})$	
interface	$b_l = b_l(b_{l-1}; K'_l, K'_{l-1})$	
	$\psi_l^+ = b_l$	
atmospheric	$\vdots$	back subsitution
	$\psi_i^+ = a_i\, \psi_{i+1}^+ + b_i$	

So what are A_l, B_l?

- lowest level vertical diffusion tendency:

$$\psi_l^+ - \psi_l^- \quad = \quad -g\frac{\Delta t}{\delta p_l}\left[C'_{Ml}\left(\psi_l^+ - \psi_s^+\right) - K'_{l-1}\left(\psi_{l-1}^+ - \psi_l^+\right)\right]$$

but we don't know ψ_s as yet?

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  but we don't know ψ_s as yet?

- rewrite in terms of J_l^ψ:

$$\psi_l^+ - \psi_l^- = -g\frac{\Delta t}{\delta p_l}\left[J_l^\psi - K'_{l-1}\left(\psi_{l-1}^+ - \psi_l^+\right)\right]$$

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- so hide in J_l^ψ: $\psi_l^+ = A_\psi J_l^\psi + B_\psi$

Gaussian elimination

Neumann conditions

	$a_i = a_i(a_{i-1}; K'_i, K'_{i-1})$	
	$b_i = b_i(b_{i-1}; K'_i, K'_{i-1})$	
atmospheric	$\vdots$	downward sweep
	$a_l \rightarrow A_l; b_l \rightarrow B_l; impl = T(\text{INTENT OUT})$	
interface	$A_l, B_l, flag(impl = T)\ (\text{INTENT IN})$	
surface	use $A_l, B_l \Rightarrow J^\psi (\text{INTENT OUT})$	
interface	$J_l^\psi (\text{INTENT IN, OUT})$	
	$\psi_l^+ = A_\psi J_l^\psi + B_\psi$	
atmospheric	$\vdots$	back subsitution
	$\psi_i^+ = a_i\, \psi_{i+1}^+ + b_i$	

The surface ALADIN-ARPEGE

- linearization:

$$
\begin{aligned}
J^S &= C_{H1}\, S_l^+ + C_{H2}\, q_l^+ + C_{H3}\, T_s^+ + C_{H4} \\
J^q &= C_{E1}\, S_l^+ + C_{E2}\, q_l^+ + C_{E3}\, T_s^+ + C_{E4}
\end{aligned}
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\end{aligned}
$$

-

$$
\frac{\partial T_s}{\partial t} = \frac{2\pi}{\tau}\left(T_p - T_s^+\right) + C_s \left\{ \left(F'_\dagger - \epsilon\sigma {T_s^+}^4 \right) + F_\odot (1-\alpha) + \mathsf{FLE} + \mathsf{FCS} \right\}
$$

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$$T_s^+ = D_{T1}\, S_l^+ + D_{T2}\, q_l^+ + D_{T4}$$

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- subsitution

$$
\begin{aligned}
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J^q &= C_{E1}\,S_l^+ + C_{E2}\,q_l^+ + C_{E3}\,\left(D_{T1}\,S_l^+ + D_{T2}\,q_l^+ + D_{T4}\right) + C_{E4}
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$$

The surface ALADIN-ARPEGE

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- use A_l, B_l to substitute S_l^+, q_l^+:

$$S_l^+ = A_S\, J^S + B_S$$
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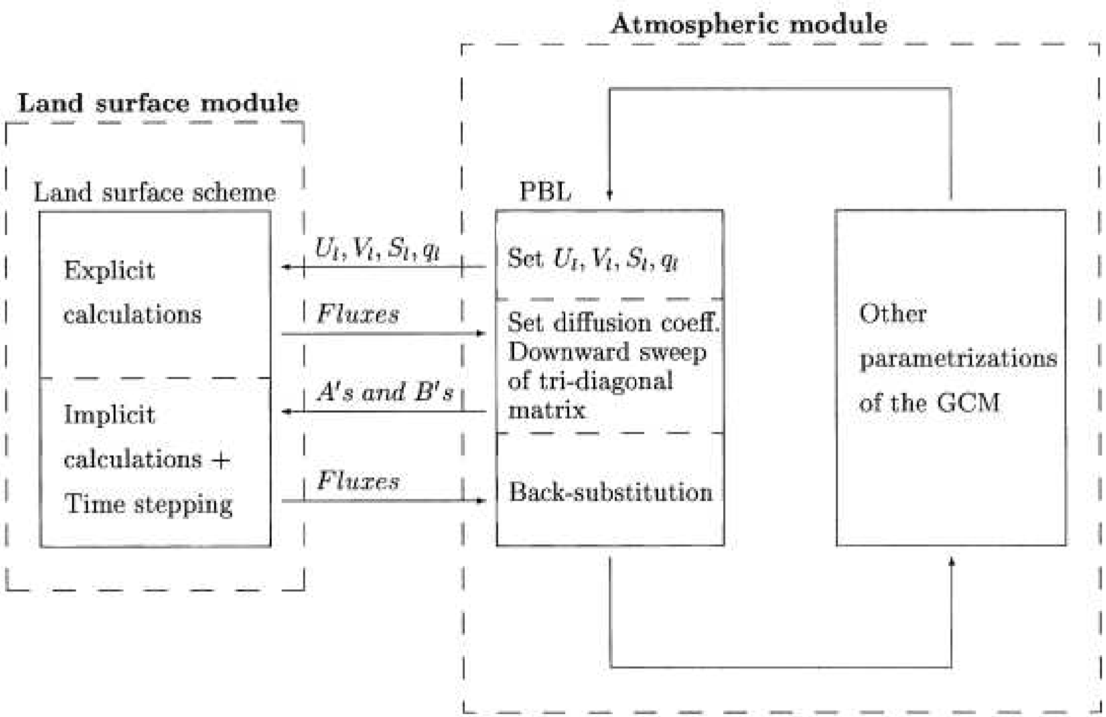
- $\Rightarrow$ 2 linear Eqs. with 2 unknowns J^S, J^q(INTENT OUT)

Best, Beljaars, Polcher, Viterbo, 2004



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A_U, B_U (east–west wind component)	Moisture flux (kg m^{-2} s^{-1})
A_V, B_V (north–south wind component)	Surface radiative temperature (K)

5 questions

- S vs. $c_p\,\theta$

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- $c_p(q)$ and $L(T)$

the choice of S vs. $c_p\theta$

- ALADIN-ARPEGE (Giordani 1993), ECMWF (Best et al.): dry static energy

$$S = c_p T + \phi$$

the choice of S vs. $c_p\theta$

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- ARPEGE-Climate (Gibelin 2004), SURFEX: sensible heat

$$c_{ps}\theta_s = c_{ps}\, T_s\, \pi_s^+ \,, \qquad \pi_s^+ = \left(\frac{p_{00}}{p_s}\right)^{\frac{R}{c_{ps}}}$$

the choice of S vs. $c_p\theta$

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$$c_{ps}\theta_s = c_{ps}\, T_s\, \pi_s^+ \,, \qquad \pi_s^+ = \left(\frac{p_{00}}{p_s}\right)^{\frac{R}{c_{ps}}}$$

- transformation: $c_{ps}\theta_s = (S_s - \phi_s)\,\pi_s$

S vs. $c_p\theta$: be my guest?

- What if we would like to plug a $c_p\theta$ module into a S module or vice versa?

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- What if we would like to plug a $c_p\theta$ module into a S module or vice versa?
- Keeping logical switches in both modules is not an option: (redundant) code maintenance will increase.

S vs. $c_p\theta$: be my guest?

- What if we would like to plug a $c_p\theta$ module into a S module or vice versa?
- Keeping logical switches in both modules is not an option: (redundant) code maintenance will increase.
- Can it be done in the interface?

the choice of S vs. $c_p\theta$ in the interface?

- Go from J^S to J^θ

$$
\begin{aligned}
J_l^S &= \rho C_H |\mathbf{V}| \left(S_l^+ - S_s^+\right) \\
J_l^\theta &= \rho C_H |\mathbf{V}| \left(c_{pl}^+ \theta_l^+ - c_{ps}^+ \theta_s^+\right) \\
J_l^\theta &= \pi_s^+ J_l^S + \rho C_H |\mathbf{V}| \left\{ S_l^+ \left(\pi_l^+ - \pi_s^+\right) + \phi_s^+ \pi_s^+ - \phi_l^+ \pi_l^+ \right\}
\end{aligned}
$$

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J_l^\theta &= \pi_s^+ J_l^S + \rho C_H|\mathbf{V}|\left\{S_l^+\left(\pi_l^+ - \pi_s^+\right) + \phi_s^+\pi_s^+ - \phi_l^+\pi_l^+\right\}
\end{aligned}
$$

- Go from A_S, B_S to A_θ, B_θ

$$
\begin{aligned}
S_l^+ &= A_S J_l^S + B_S \\
c_p\theta_l^+ &= A_\theta J_l^\theta + B_\theta
\end{aligned}
$$

the choice of S vs. $c_p\theta$ in the interface?

- we get an invertible linear transformation

$$\begin{pmatrix} A_S \\ B_S \end{pmatrix} = \frac{1}{\pi_l^+ + \rho C_H|\mathbf{V}|\left(\pi_s^+ - \pi_l^+\right)} \begin{pmatrix} \pi_s^+ & 0 \\ \rho C_H|\mathbf{V}|\left(\phi_s^+\pi_s^+ - \phi_l^+\pi_l^+\right) & 1 \end{pmatrix} \begin{pmatrix} A_\theta \\ B_\theta \end{pmatrix} + \begin{pmatrix} 0 \\ \phi_l^+\pi_l^+ \end{pmatrix}$$

the choice of S vs. $c_p\theta$ in the interface?

- we get an invertible linear transformation

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- what about c_p^+ in π^+?

the choice of S vs. $c_p\theta$ in the interface?

- we get an invertible linear transformation

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- what about c_p^+ in π^+?
- make the same compromise as in ARPEGE Climate, Gibelin (2004): take it at $-$. in that case it was necessary to transform T_s (which we need for $\frac{\partial T_s}{\partial t} = \ldots$) to θ.

So ... be my guest

- after the call to the surface scheme, the interface can transform the fluxes because it still “remembers” the A and B coefficients!

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- after the call to the surface scheme, the interface can transform the fluxes because it still “remembers” the A and B coefficients!
- so neither the atmospheric module nor the surface module have to know about the choice of the “other world” and still say: “be my guest”

So ... be my guest

- after the call to the surface scheme, the interface can transform the fluxes because it still “remembers” the A and B coefficients!
- so neither the atmospheric module nor the surface module have to know about the choice of the “other world” and still say: “be my guest”
- if this is feasible: the development on SURFEX can completely ignore the matter and be still completely “Best compliant”

The $q_l T_s^+$ term in ALADIN-ARPEGE

Documentation of L. Gerard (2001)

$$\begin{bmatrix} 1+w_{1,1} & -w1,1 & & & & (0) \\ -w_{1,2} & 1+w_{1,2}+w_{2,2} & -w_{2,2} & & & \\ & & & \begin{bmatrix} (A) \end{bmatrix} & & \\ & & & & & -w_{1,2} \\ (0) & & & & -w_{1,1} & 1+w_{1,1} \end{bmatrix} \left\{ \begin{array}{c} s_1^+ \\ s_2^+ \\ .. \\ \left\{ \begin{array}{c} s_L^+ \\ T_s^+ \\ q_L^+ \end{array} \right\} \\ .. \\ q_2^+ \\ q_1^+ \end{array} \right\}$$

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“Parametrisations physique ARPEGE-ALADIN”, p16-6: In contradiction to the principle of linearization we only consider the first term HQq_{vN} in the $-$ index

The $q_l T_s^+$ term in ALADIN-ARPEGE

- The "surface" part

$$\begin{bmatrix} 1 + w_{L-1,L} + w_{L,L} & -w_{L,L}\mathsf{CTVS} & 0^* \\ -\mathsf{CSVT} & 1 + \mathsf{CTVT} & -\mathsf{CQVT} \\ 0 & -w_{L,L}\mathsf{CTVQ} & 1 + w_{L-1,L} + w_{L,L}\mathsf{CQVQ} \end{bmatrix} \begin{Bmatrix} s_L^+ \\ T_s^+ \\ q_L^+ \end{Bmatrix}$$

Ignoring the part proportional to

$$q_l^+ T_s^+ \sim 0^*$$

to obtain a tridiagonal matrix.

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- Following Best et al., this is NOT necessary!

Antifibrillation

- problem: PCDROV surface exchange coeffficient

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- In ALADIN-ARPEGE one computes with modified exchange coefficients PCDROV $*$ PXDROV
- If we follow this approach, then we compute the fluxes with modified exchange coefficients.
- In an externalisation as Best et al., the fluxes are computed by the surface scheme, but PXDROV depends on the layers above, i.e. atmospheric module.

Antifibrillation: however ...

- Bénard et al. (2000): let the explicitness

$$\begin{aligned}\frac{\partial \psi}{\partial t} &= -g\frac{\partial}{\partial p}\left[(1-\beta)\,K\frac{\partial \psi}{\partial p} + \beta K\frac{\partial \psi}{\partial p}^{+}\right]\\ &= g\frac{\partial}{\partial p}\left[(1-\beta)\,J_{\psi} + \beta J_{\psi}^{+}\right]\end{aligned}$$

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\end{aligned}
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- So we can also multiply the fluxes.
- If we can compute β entirely in the atmospheric module we can then multipy the received fluxes.

Antifibrillation: computation β

- Bénard et al. (2000): situation dependent β

$$A(\beta, K, \alpha)\tau^2 + B(\beta, K, \alpha)\tau + C(\beta, K, \alpha) = 0$$

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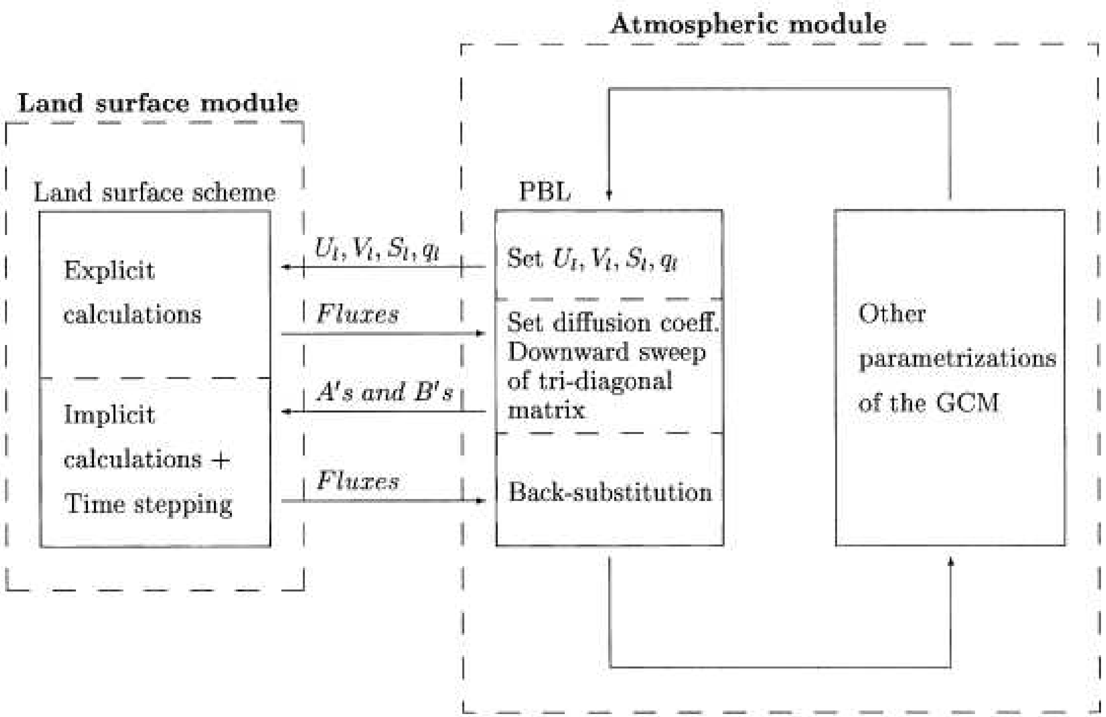
- ADVANTAGE: the surface does not have to care about antifi brillation. It only has to answer to the enquiries.

Best, Beljaars, Polcher, Viterbo, 2004



+ Enquiry mode

Best, Beljaars, Polcher, Viterbo, 2004

TABLE 1. Variables to be passed within the coupling scheme. This table does not include the domain-describing variables such as geographical coordinates, time, or height of atmospheric levels. The surface scheme should respond with output dependent on a mode flag (enquiry mode, explicit mode, or time-stepping mode). The output variables are all tile averaged.

Input variables (from atmospheric model)	Output variables (from surface scheme)
Lowest-level east–west wind speed (m s^{-1})	Enquiry mode
Lowest-level north–south wind speed (m s^{-1})	Surface albedo (—)
Lowest-level dry static energy (J kg^{-1})	Surface emissivity (—)
Lowest-level specific humidity (kg kg^{-1})	Surface radiative temperature (K)
Surface pressure (Pa)	Explict mode
Solar zenith angle (°)	East–west momentum flux (N m^{-2})
Net surface shortwave flux (W m^{-2})	North–south momentum flux (N m^{-2})
Fraction of diffuse shortwave radiation (—)	Sensible heat flux (W m^{-2})
Downwelling longwave radiation (W m^{-2})	Latent heat flux (W m^{-2})
Rainfall (kg m^{-2} s^{-1})	Moisture flux (kg m^{-2} s^{-1})
Snowfall (kg m^{-2} s^{-1})	Time-stepping mode
Subgrid variance of rainfall (kg m^{-2} s^{-1})	East–west momentum flux (N m^{-2})
Subgrid variance of snowfall (kg m^{-2} s^{-1})	North–south momentum flux (N m^{-2})
A_s, B_s (dry static energy)	Sensible heat flux (W m^{-2})
$A_{\bar{q}}$, $B_{\bar{q}}$ (specific humidity)	Latent heat flux (W m^{-2})
A_U, B_U (east–west wind component)	Moisture flux (kg m^{-2} s^{-1})
A_V, B_V (north–south wind component)	Surface radiative temperature (K)

$A_U = A_V$?

- What is the impact of this choice?

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- in ALADIN-ARPEGE c_p and L depend on q and T resp.
- in SURFEX they do not
- this poses the first question: what kind of flux is provided from SURFEX to AROME?

Equations: $c_p(q)$ and $L(T)$

- Lecture J.-F. Geleyn Prague: “strange new term”

$$c_p \frac{dT}{dt} = \frac{1}{\rho}\frac{dp}{dt} - \frac{1}{\rho}\frac{dR_{ad}}{dz} - \sum_k \dot{q}_k h_k + T \sum_k c_{pk} \frac{1}{\rho}\frac{\partial}{\partial z} J_{q_k} - \frac{1}{\rho}\frac{\partial}{\partial z} J_s + D_{is}$$

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- enthalpy change (see Girard 1995 for how to treat this) due to mass changes from incoming particles

Equations: $c_p(q)$ and $L(T)$ study this?

- fundamental reason: consistency of the equations of the atmosphere and the surface (see atmospheric Eqs. in ALADIN-AROME-ALARO and what is the meaning of the variables)

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- fundamental reason: consistency of the equations of the atmosphere and the surface (see atmospheric Eqs. in ALADIN-AROME-ALARO and what is the meaning of the variables)
- quality of the model: does excluding this dependence have an impact on the quality of the forecast?

5 questions

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  - would provide guidelines for the coupling of SURFEX in AROME, ALARO
  - but can only be more solid if tested in the model ...
- can we already get answers before the actual coupling of SURFEX?

job to do for getting answers

In ALADIN

- reorganize ACDIFUS as Best et al., test without antifi brillation: difference should be numerical noise guaranteeing a smooth transition and systematic validation

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- add interface + switch $S \leftrightarrow \theta$: can we keep the link with ECMWF?
- add enquiry mode, antibrillation: what is the best way and does the surface has to be bothered?