WORKING GROUP 1: LAND SURFACE MODELS

1.1 RECOMMENDATIONS AND RATIONALE

The working group on land surface models reached a broad consensus on a suite of recommendations. We chose to split these recommendations into three levels of priority: short term (in time for the ERA40); medium term (high priority but not deliverable in time for ERA40, but deliverable in around two years); and long term (broader and more fundamental changes in approach which requires significant work and further development in the basic understanding of the processes).

We note that our recommendations supplement the conclusions of the La Jolla workshop which was jointly organised by IGBP-BAHC and GEWEX in 1997, and which discussed future prospects for the evaluation of land surface schemes, specifically, the modelling of soil moisture, runoff and plant physiology. The future need for data was also discussed. In all three modelling topics it was concluded that it was necessary to refocus effort from vertical complexity to a better representation of horizontal heterogeneities in current schemes. It was believed that this would best be achieved by an explicit representation of subgrid areas that have different surface characteristics (tiles). We concur with these conclusions, but note that this is best targeted by ECMWF in its long term planning strategy rather than any short or medium term objectives.

1.2 SHORT TERM RECOMMENDATIONS (8 MONTHS)

These recommendations are designed to be deliverable in time for the ERA 40.

1. *Implement a new snow scheme with consistent snow analysis.*

Before coping more explicitly with the important issue of snow cover heterogeneity (see medium-term recommendations below), a series of more basic issues must be considered. This includes snow thermal properties as a function of density, ageing and settling processes within the snow pack through the introduction of snow albedo and snow density, fractional snow cover as a function of vegetation height, as well as sub-grid scale orography. With a more realistic snow model, ECMWF should be in a better position to perform data assimilation: observed snow depth can be related in a more physical way to the model state variable (snow mass) and less weight could be given to the relaxation to climatology and persistence on the assimilation step, which in turn would improve interannual variability in data rich areas.

2. *Account for low surface albedo of forest in the presence of snow.*

The marked distinction of surface albedo in the presence of snow between forest areas and prairies is taken into account by some models, including the ECMWF model since 1996. The introduction of that effect in the ECMWF model was accompanied by a substantial reduction of the low level temperature bias over the boreal forests in spring, corresponding to a larger fraction of solar energy available to heat the surface. However, the current implementation at ECMWF allows for the energy available at the top of the canopy to be given back to the atmosphere as evaporation at the potential rate, which is clearly not correct. A better way of doing the energy budget of snow under the canopy, while still keeping the beneficial low albedo effects, is needed.

3. *Include control of canopy resistance with soil temperature and/or liquid soil moisture.*

Most forests of temperate regions switch in mid-spring from a very low to a high evaporation fraction, with impacts on boundary-layer development and therefore impacts on the lower troposphere structure. The transition period is very short, of order few weeks at most. A simple way of accounting for this in models is to have an additional resistance term that depends on temperature or, alternatively, to make the soil moisture stress dependent on liquid soil water rather than total soil water.

4. *Assess the global albedo data set and examine alternative products.*

The albedo data set used currently by ECMWF is based on a global distribution of vegetation types (*Dorman and Sellers,* 1989) and is known to have large errors over arid and semi-arid regions outside of North Africa and Arabia. The data set assigns a single soil albedo to all bare soil grid points. That albedo is based on the bright sandy soils of the Sahara, but is also applied over much of central Asia, southern Africa, Australia, and the deserts of the Americas. In these regions, positive albedo errors can range from 0.05-0.20, compared to a consensus of albedo data sets from the ISLSCP Initiative I CD-ROM (*Meeson et al.,* 1995), including ISCCP and ERBE products. These errors can lead to shortfalls in absorbed shortwave radiation of more than 100 Wm^{-2}.

It is recommended that another spatially and seasonally varying data set of snow-free surface albedo be adopted. The albedo data set should be consistent with the data set of vegetation distribution and seasonality used. Even if spatially-varying vegetation properties are not adopted at the same time as the albedo changes, the data sets should be selected at the same time. One self-consistent data set available now is the ISLSCP 1E global data set, which includes a monthly albedo data set derived for SiB2. However, for higher resolution, a vegetation mask based on the 1 km IGBP/USGS vegetation data set would be more appropriate, and allow for the future inclusion of sub-grid heterogeneity.

The correction of albedo will probably have the largest impact over Asia, since this area has the largest contiguous region of large errors. Increased surface temperature over the Tibetan Plateau during summer will result, increasing tropospheric temperatures and strengthening the ridge over the region. This will likely affect the simulation of the Asian monsoon.

1.3 MEDIUM TERM RECOMMENDATIONS (2 YEARS)

1. *Include geographically variable vegetation properties.*

2. *Consider and test additional dependencies on a Jarvis canopy resistance model, on top of the current dependence on PAR and root zone soil wetness.*

3. *Separate the energy balance of snow and canopy.*

4. *Implement a surface tile structure.*

The evolution of Soil-Vegetation-Atmosphere Transfer Schemes (SVATS) for NWP models and GCMs over the last two decades has primarily embraced a 1-D vertical column perspective. During this time, considerable vertical complexity has emerged in SVATS in terms of the representation of soil hydrology and thermodynamics (multi-layer soils, Darcian flow, thermal diffusion equation), surface energy balance, vegetation canopy processes (fluxes of water/heat/carbon, flux resistances, canopy interception, canopy radiative transfers, canopy albedo, LAI seasonality, etc), and atmospheric surface layer treatments (e.g. roughness length for heat).

However, this vertical complexity is conceptually most appropriate at the plot scales, and is less appropriate for model grid cell scales of tens to hundreds of kilometres. At these scales, considerable sub-grid heterogeneity exists in vegetation state, soil type, topography, and slope. Hence, a widely recognised current need in the SVAT community, enunciated in the conclusions of the La Jolla workshop, is to promote suitable balanced enhancements in horizontal complexity. A majority of this working group and a significant segment of the SVAT community believes a "tile" or mosaic approach is an effective method to address horizontal sub-grid heteorogeneity. Herein, the grid cell of the parent atmospheric forcing model is divided into a set of sub-grid tiles, distinguished by surface type and soil type. Such tiling is envisioned to embrace about 3-6 different surface classes, such as: bare soil; dominant vegetation class; secondary vegetation class; inland water (lakes); urban; permanently saturated (e.g. marsh).

The primary motivation for the tiling approach is to increase the physical realism of modelled surface energy and water fluxes. In the area of energy fluxes, improved realism is expected from solving for a distinct energy balance, energy fluxes, and skin temperature over each tile. The separate tile skin temperatures in particular are expected to yield notable improvements in the sensible, ground, and upwelling longwave flux, and hence improvements in the latent heat flux.

Finally, the working group believes the distinct tile skin temperatures will improve a model's ability to replicate satellite-derived radiative skin temperatures, by better representing the skin temperature heterogeneity that is implicitly present in a spatially integrated sense in the satellite-derived skin temperature. The upward longwave radiation is a non-linear function of skin temperature and therefore in a satellite field of view, the hotter skin temperatures have more weight in the retrieved temperature than the cold skin temperatures. It is clear that satellite-derived skin temperatures are increasingly important in land-surface modelling for both validation and assimilation.

In the case of water fluxes, improved realism is expected from distinct treatments of the infiltration over each tile. Such infiltration improvements may require that separate soil state variables (moisture/temperature) be carried for each tile. At an even higher level of complexity, separate secondary tiles of soil class may be needed for each tile of surface class.

The latter prospect of separate soil states for either the primary surface tiles or secondary soil class tiles significantly raises the level of complexity. Research is needed to demonstrate to what extent infiltration, runoff, and energy flux improvements stem from carrying separate tile soil states, as opposed to the opposite approach of adopting whole grid-cell "effective" parameters for hydrologic conductivity and diffusivity.

Finally, separate tile soil states significantly complicate the procedures for assimilation soil moisture information, whether that be from shelter observations, satellite skin temperature, or satellite microwave soil moisture.

This working group recommends that, in the near term, pending further supporting research, ECMWF should first pursue a modest tiling approach, embracing distinct sub-grid surface classes , with a common soil state, as a first step, but maintain maximum code flexibility to allow easy implementation of more complex tiling approaches in the future if required.

5. Assess the use of the tile structure in the presence of extreme classes.

After the tiling mechanism is built in the code, it should be tested in the presence of extreme classes, such as urban areas, lakes, and permanently saturated regions. A proper handling of these classes might require the consideration of separate boundary-layer fluxes over each tile.

6. Investigate the level of complexity required in the modelling of soil temperature.

Recent study of the thermal effects of soil water phase changes in many atmospheric global models has shown the importance of the soil thermal processes in the control of wintertime screen temperatures.

Even in the absence of phase changes, the evolution of soil temperature and the correct treatment of the soil heat flux is likely to be a key factor in controlling the screen-temperatures in the cold season and night time all-year around. A recent paper has shown the seasonal evolution of the soil temperature to be crucially affected by the dependence of thermal diffusivity on soil water in wet conditions (*Peters-Lidard et al.,* 1998). The same paper has shown that many models, including the ECMWF model, have a poor representation of that dependence.

Many models solve the soil heat transfer equation with a vertical discretization involving 4-5 layers with a total depth of the order of 4 m, and a no-flux low boundary condition at the bottom. Given that the penetration depth (the e-folding depth of the annual heat wave) is of the same order, it is unclear if those discretization practices significantly affect the solution.

Because deep soil temperature acts as an integrator of errors in the forcing (or the land surface scheme) during the previous few weeks, it might be affected by drift in NWP or long-term integrations. Mean annual errors of a few Wm^{-2} in the net surface heat flux might induce an error in the soil mean temperature of a few degrees in the uppermost 4 metres.

Observations of soil temperature might be very useful for validation and diagnosis of model problems. It has few of the ambiguity problems of soil wetness and its measurements are probably representative of larger spatial scales. Soil temperature is regularly measured by the same SYNOP stations that disseminate the screen-level variables and if those values were disseminated in real-time they could even be used in data assimilation, keeping the seasonal time scale in the soil energy under control.

The committee recommends the use of initially long term one-column or 0-column integrations forced by observations in order to assess how small errors in the forcing might affect the annual mean temperature. A clear physical understanding of what determines annual mean soil temperature and how that relates to annual mean screen-level temperature is needed. It is likely that these integrations will demonstrate a need to at least double the current number of soil layers included in the EMCWF model.

1.4 LONG TERM RECOMMENDATIONS

1. Refocus attention towards horizontal complexity. This is mainly to help the modelling of runoff and soil moisture which is likely to be important in seasonal forecasting.

A proper strategy for land surface model development must be guided by two preliminary steps: (i) the isolation of the processes that contribute the most to the important aspects of model behaviour, and (ii) the determination of which of these processes currently has the weakest representation in the model. The danger is of course that the more poorly modelled components of the model are neglected, whereas the well developed model components are developed even further.

Much of the "complexity imbalance" in most land surface models today involves the over-development of vertical, one-dimensional physics relative to the treatment of complexity in the horizontal.

Consider the example of long-term (seasonal to interannual) forecasting, which depends strongly on a model's ability to forecast the evolution of soil moisture. The severest limitation to this forecast capability, it can be argued, is the model's inability to resolve subgrid variability in soil moisture and its effects on runoff and evaporation production. If this is indeed true, improvement in forecast capability through an improved treatment of vertical physics will be minimal. Model development should instead focus on the horizontal heterogeneity issue.

Soil moisture heterogeneity may be less important for short-term weather forecasting, especially if realistic average soil moisture contents can be maintained through data assimilation. A proper treatment of the horizontal variability of other surface characteristics, however, may still be critical. In particular, horizontal variations in vegetation/soil type and snow cover must be represented to generate realistic surface fluxes.

Development of the treatment of horizontal heterogeneity has proceeded along two lines. The first focuses on the effects of heterogeneous surface types and land cover by using a "mosaic" or "tiling" strategy. This approach can significantly improve the simulation of evaporation and the surface energy balance, particularly on the time scales of NWP. The second, and less well developed, line attempts to represent the heterogeneity of hydrological regimes, particularly as it is affected by sub-grid topographic variance. This line targets the surface water budget and the simulation of runoff, and is more important for seasonal and longer time scales. It is also a natural framework to consider the correct handling of fast runoff processes vs. slow runoff mechanisms.

At this stage, our knowledge of the appropriate methods for incorporating heterogeneity into the hydrological component of land-surface schemes is limited, but land-surface models are working on various methods that show potential. We recommend that ECMWF provide a watching brief on these developments, over the next 3-5 years, and if appropriate incorporate those methods which prove successful.

2. *Heterogeneity of snow cover.*

A long-term objective of weather and climate model development groups should be to improve the representation of subgrid snow distributions within the models. In order to realistically represent seasonal snow within the context of atmospheric models used to simulate weather and climate, the fractional snow-covered area within each grid cell must be known. This can be determined through knowledge of the subgrid snow distribution, and the computed snowmelt rates (*Liston*, this workshop). This subgrid snow distribution is strongly dependent upon subgrid orographic precipitation processes, and any subgrid snow distribution methodology is expected to also require a parametrization of orographic precipitation processes. We believe that improvements in atmospheric model simulations will be made by changing how the horizontal distribution of snow is accounted for, and that this is potentially more important than possible improvements in the snow model's vertical resolution. Such changes in the representation of spatial snow distributions are expected to improve the model simulation of seasonal snow and the associated interactions with the atmosphere, however at the present time it is uncertain how to incorporate these improvements. We recommend therefore that ECMWF provide a watching brief on the research efforts with the intention of incorporating those developments which prove successful.

3. *Explicit radiative transfer model in the canopy.*

In the long term a full bidirectional reflectance distribution function calculation will free the model from a chosen albedo "climatology" and will enable the assimilation of the structure of the vegetation. The vegetation structural parameters needed for this calculation, either taken from observation or from more detailed models, can in this way be corrected through assimilation. The corrected parameters can then contribute to a better modelling of the surface fluxes.

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WORKING GROUP 2: USE OF DATA SETS

2.1 INTRODUCTION

This group reviewed the ECMWF plans for model development and the data sets available for model development and evaluation. Our recommendations are within the text.

1 ECMWF plans.

The planned model changes before ERA-40 and the longer term work were reviewed. The list of short term changes prior to this workshop included:

- new snow model with consistent snow analysis.
- better analysis of soil moisture.
- better energy balance of low albedo forest with snow.
- inclusion of soil temperature in stomatal control.

In the longer term it was planned to:

- add high vegetation as new subgrid fraction with multiple resistance network to provide coupling with snow or bare soil under canopy.
- delete coupling of T_{skin} between different sub-areas (introduce cloud free T_{skin}).
- replace single vegetation type by geographical distribution of vegetation type.
- use more complex stress functions dependent on vegetation type (e.g. include dependence on atmospheric humidity, diffuse radiation), and seasonal cycle.
- increase soil water reservoir (rooting depth dependent on vegetation type).
- compare satellite skin temperatures and SYNOP screen level temperatures with the model and optimize parameters (it might be necessary to define a "cloud-free T_{skin}" in the model in order to do a clean comparison with the satellite observations).

These plans received strong endorsement from the working group. Other models such as HIRLAM, ARPEGE and the ETA model have shown improvements in forecast skill from a more detailed land surface type classification. The working group also concluded that the surface runoff, and spring runoff from snow melt needed improvement. Furthermore it recommended that a distribution of vegetation types and a seasonal cycle be introduced into the land-surface scheme for ERA-40, even if this means delaying the production run of ERA-40 a few months. During the discussion in the plenary session it was emphasized that the timing of ERA-40 was constrained by other aspects and that therefore the recommended model development might not be ready.

2.2 OBSERVATIONAL DATA

A land surface vegetation climatology, including the seasonal cycle, is now available from NESDIS as a model climate field. Soil data is available from FAO data sets. In the long term the integration of greenness observations from satellites should be investigated.

1 Model testing.

Abundant long term data sets are now available for model development and evaluation over different vegetation types. The centre should acquire these data and archive co-located model time series. Many of the new "FLUXNET" sites are over forests, and the primary motivation of the scientists in this community is to study the annual carbon balance rather than the energy and water balances needed for NWP. ECMWF should therefore encourage process oriented hydrometeorological analyses of these data, and also search out data for each of the vegetation types in the ECMWF model.

Testing should be carried out using the single column version of the ECMWF global model. Long runs of data are needed to test the representation of the seasonal and interannual variation. The model should be able to represent the different responses of a drying soil profile, with maximum soil water at depth, and a wetting profile, which may have the same amount of water in the profile, but with maximum soil water close to the surface.

The ECMWF land surface scheme can be tested using the PILPS 2(D) Valdai data, to evaluate its ability to simulate the seasonal cycle and intraseasonal variability in a climate with seasonal snow and seasonally frozen soil.

The land surface scheme might also be tested as part of the Global Soil Wetness Project to allow evaluation of the runoff.

The operational GOES skin temperature and surface short wave radiation products should be used for model evaluation.

2. *Data available for evaluating ERA-40.*

Robock et al. (1995) have a 40-year data set of soil moisture, beginning in 1958, for the agricultural region of the former Soviet Union. These consist of three times per month gravimetric observations at 10-cm vertical resolution down to 1 metre, from April through October, separately for spring cereals and winter cereals. The Global Soil Moisture Data Bank also has several hundred other soil moisture stations with shorter records, but all at least six years long.

The World Snow and Ice Data Centre (directed by Roger Barry, University of Colorado) has recently produced a data set of Russian snow observations at hundreds of stations, that extend back before 1958. They include snow depth and snow density (snow water equivalent), and could be assimilated into ERA-40 or used for validation.

3 Idealised single column simulations.

We recommend that a single column version of the Centre's land-surface and boundary-layer model be used to understand the equilibrium diurnal climate over land as a function of the land-surface boundary condition, including soil water, and free tropospheric variables. This could lead to improved understanding of the model diurnal cycle errors, and the coupling of the boundary layer and shallow cloud field to the surface.

2.3 HYDROLOGICAL ISSUES

There are a number of hydrological issues which need to be addressed in both the short and long term. Deficiencies in the seasonal water balance in the model may well impact the seasonal forecasting capability as well as the interannual variability. The involvement of the centre in GEWEX experiments such as GCIP has led to a better understanding of the model hydrology, and this should be continued. The centre should clarify its long-term objectives in the area of prediction of runoff and streamflow.

1 Surface runoff.

At present, the surface runoff component in the ECMWF model does not function properly. The formulation used is based on an infiltration excess mechanism; if precipitation exceeds the infiltration capacity of the soil over the whole of the grid square, then runoff occurs. The main problem with this formulation is the spatial averaging of precipitation and infiltration; when in reality, runoff is produced when the infiltration capacity of the soil over part of the grid square is exceeded by the rainfall intensity.

This formulation could be easily upgraded by adopting a distribution function approach as implemented in the ECHAM model by *Dümenil and Todini* (1992) and in the VIC model by *Wood et al.* (1992). With these formulations, a distribution function is used to describe the variation in infiltration and/or soil moisture storage capacity across the grid square. Analytical expressions exist for spatially integrated runoff, given forcing by precipitation and meteorological data.

2 Spring runoff/water balance.

Model simulation of spring runoff is currently poor. Consequently, the soil moisture reservoir is not replenished, which introduces a seasonal error into evaporation. The upgrading of the snow melt component of the model to deal with high and low vegetation (with different types) will provide an opportunity to improve seasonal runoff; this will require a means of apportioning snow melt between soil moisture reservoir replenishment, and river runoff.

3 Heterogeneity and water balance conservation at basin scales.

The impact of spatial heterogeneity in soil moisture, evaporation and runoff at the sub-grid scale on the ECMWF forecasting performance is not well understood. In the atmosphere, the boundary layer integrates the surface fluxes over a considerable advection distance under unstable conditions. However, it is felt that, since the land surface is closely coupled to the atmosphere, spatial heterogeneity in vegetation, soils etc may have an important influence on the spatial variability of evaporation, and on the conservation of the water balance across the full range of basin scales. While models exist which can properly characterise this sub-grid heterogeneity, as well as the larger scale lateral transfers associated with ground water and river runoff, the data are not available globally to implement such models. However, it is expected that the necessary data products will become available in the next 5-10 years to facilitate the implementation of a new generation of land surface models in which heterogeneity and lateral transfers are fully accounted for, and water balance conservation is achieved at all scales.

In order to gain insight into the current deficiencies of the water balance in the ECMWF model, and the importance of heterogeneity, a comparison could be carried out between the results obtained by the spatially distributed physically-based UP model of the Arkansas-Red basin (*Kilsby et al.*, 1998) and the results obtained from the ECMWF reanalysis data for the same basin (*Betts et al.*, 1998). The latter work has shown that the water balance error in the model is of the same order as the nudging term (100 mm), so the proposed model comparison could prove instructive as to the sources of this error.

4 Agricultural terrain.

One land class will be agricultural, and the Centre should acquire an archive related to crop type and crop parameters, as well as irrigation, drainage and cultivation practice information, as increasingly evaporation from agricultural regions is being controlled.

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WORKING GROUP 3: DATA ASSIMILATION OF LAND SURFACE PARAMETERS

3.1 GENERAL CONSIDERATIONS

Global initialization of prognostic variables for land surface parametrization (LSP) schemes has been recognized as an important issue for medium range weather forecasts (to improve weather parameters), seasonal prediction (to capture part of the low frequency variability of the atmosphere), and reanalysis projects (to get realistic surface climatological products accounting for seasonal and interannual variability).

The important variables to initialize are those having long time scales of variations (from one week to several months) :

- soil moisture within the root zone (driving surface evapotranspiration which is a key element to accurately represent surface evaporative fraction).
- snow water equivalent (which has a strong impact on the surface energy balance through albedo effects and on the hydrological balance through snowmelt process).
- deep soil temperature.

The initialization problem depends strongly on the representation of processes in LSP schemes and on the specification of physiographic data sets. Indeed, the initialization of soil variables should not compensate for model biases due to an incorrect specification of surface properties or to an inadequate description of physical processes. Accurate estimations (model, observations) of downward solar and longwave radiations (cloudiness) and precipitation are of primary importance for driving LSP schemes.

The current sources of data to initialize LSP schemes mostly comes from SYNOP reports (which can pose representativeness problems). Current operational satellites could already provide useful information on land surfaces in the near future (fractional snow cover, fractional saturated soils, radiometric surface temperature) before the availability of new satellite missions (microwave L-band radiometers).

3.2 SNOW

In the short term, it is recommended to improve the current ECMWF snow analysis scheme for the reanalysis project (ERA-40) by:

- using a more realistic snow depth climatology (e.g. USAF).
- using more realistic snow density values.
- performing a 2-m temperature analysis to better describe the snowmelt process.

In the longer term, the snow parametrization scheme should be improved by describing snow density and snow albedo as prognostic variables, following Météo-France developments. With an improved scheme, snow depth from the forecast model could be used as first-guess in the analysis scheme. The necessity for a vertical description of the snow pack should be evaluated. However, the complexity of the snow scheme should be compatible with what can be observed. A possible alternative to the multi-layer approach could be to discriminate between wet and dry snow.

The representativeness of snow depth observations in mountainous areas should be evaluated (e.g. over the Alps).

Information on fractional snow cover and snow albedos derived from satellite should be included in the analysis scheme.

The successive correction method appears suitable for snow analysis. Optimum interpolation using anisotropic horizontal structure functions based on topography and land/sea contrast could be developed following ideas from the HIRLAM group.

It is recommended to encourage Space Agencies to design a radiometer suitable for measuring snow water equivalent at a 15 km resolution.

3.3 SOIL MOISTURE

Some weaknesses of the ECWMF soil moisture analysis scheme have been identified (diurnal cycle of increments, large increments after rainy events). It is likely that part of the corrections compensate for a variety of land and atmospheric model errors (e.g. constant canopy resistance, lack of seasonal variations in the vegetation properties,...). Recent improvements in the representation of clouds and radiation in the ECMWF model have shown that soil moisture increments are currently weaker than when the nudging technique was put in operations.

It is recognized that simulating a realistic or observable soil moisture may not produce observable surface fluxes due to model imperfections. However, the analysis of observable soil moisture will have significant implications for secondary applications (such as flood prediction), and for model validation. Therefore, if the analysis of an observable soil moisture becomes a desired goal, it is thought that the use of indirect analysis methods, such as using screen-level humidity and temperature or the diurnal variations of surface skin temperature, to infer soil moisture will be less desirable than direct analysis of soil moisture observations from microwave sensors or from in-situ observations.

In the short term (ERA-40), it is recommended to:

- implement a 2-m temperature and relative humidity analysis based on optimal interpolation.
- replace the current nudging technique by an optimal interpolation with both temperature and relative humidity as predictors.
- monitor soil increments to diagnose model problems. It should be checked that corrections to various land states are done gradually, in line with their characteristic modes of temporal variability.
- evaluate the quality of the forecasts in terms of both screen-level parameters and surface fluxes using locations where turbulent fluxes are measured in routinely.

In the longer term, it is recommended to develop a 1D-Var assimilation of 2-m parameters using a boundary layer scheme coupled to a LSP scheme, following the lines of Météo-France and DWD. In this approach the sensitivity of the soil increments to 2m first guess errors is situation dependent and flow dependent and also includes the feedback from the boundary layer. Preliminary results show that the variational technique accounts for the non-linearities of the problem without apparent convergence problems. This approach can also handle the analysis of solar radiative forcing that could be provided by satellite, cloud cover (to estimate the longwave downward radiation) and surface precipitation.

The variational method is expected to be more efficient than methods based on optimum interpolation because information on the temporal evolution of screen-level parameters is taken into account. Another argument for implementing the 1D-Var method is that other sources of data, e.g. skin temperature and soil moisture retrieved from satellite, can be assimilated within this framework. However, the value for operational data assimilation has not been proven so far.

It is recommended to perform long-term comparisons of the variational method and the sequential method in one-column studies using the same model and forcing data, and to follow similar comparisons performed outside ECMWF.

It is recommended to examine qualitative information on soil moisture in regions that are not densely vegetated, on surface saturated soils provided by current microwave radiometers (SSM/I, TRMM) and on the identification of freezing/melting of soils from scatterometer data to assess their usefulness.

Future remote-sensing missions planned for measuring soil moisture (L-band radiometers: RAMSES in France and HydroStar in US) will provide only information on surface moisture content over the top 5 cm. Work should begin to examine how these measurements can be used to infer information about deep soil moisture (model of vertical correlation errors, increased vertical resolution of soil schemes near the surface, assimilation over longer periods,...)

3.4 SKIN TEMPERATURE

Radiative surface temperature over land areas is a required parameter for the assimilation of radiances from advanced operational sounders (ATOVS, IASI). The short time scales of this variable do not make its initialization in forecast models necessary. The current disagreement between observed TOVS and modelled radiances in channels sensitive to the surface requires investigations.

It is recommended to:

- examine the problem of sub-grid scale heterogeneities (effective properties, tile approach) to improve the estimation of model skin temperature, and thus reduce the representativeness problem for satellite comparison.
- include the effects of fractional open water (lakes) within model grid boxes.
- compare measurements of skin surface temperature from different radiometers (TOVS, AVHRR, ground based radiometers,...).
- investigate the necessity of including separate energy balance for vegetation canopy and bare soils (shading effects).
- investigate the need for a separate energy balance for vegetation canopy and underlying bare soil, in order to account for vegetation shading effects.

- investigate information contained in the diurnal cycle of radiative surface temperature to infer soil moisture.
- investigate spatial variability of skin temperature to infer soil moisture corrections. Since during daytime this variability is much larger than the variability of the atmospheric temperature, locations with extreme evaporative fractions may be identified. Ongoing research (outside ECMWF) focuses on the means to use these extremes for retrieving surface fluxes for intermediate regimes.
- use combined information from microwave and infra-red to help separate contributions from surface temperature and surface emissivity.

3.5 SOIL TEMPERATURES

Similar drifts to those observed for soil moisture can occur for soil temperatures during the winter season in snow-free areas (weak turbulent fluxes leading to a decoupling of the surface with the above boundary layer).
It is recommended to:

- perform a deep soil temperature analysis to improve forecasts of 2-m temperature during the winter season, and to also investigate the description of the stable boundary layer.
- investigate the information contained in night time satellite skin temperature on soil temperature
- encourage the dissemination of real-time soil temperature measurements that could be used for model evaluation and data assimilation.

3.6 VEGETATION PROPERTIES

It is recommended to improve the description of vegetation properties (vegetation cover, vegetation types, seasonality) using most recent data sets (ISLSCP CD-ROM). High vegetations (forests) and short vegetations (grass, crops) should be separated. Parameters driving surface evapotranspiration such as canopy resistance and the size of the water reservoirs should be revised. In the long term, NVDI products from operational satellites could be used to regularly update the vegetation cover in the model (as it is currently done for sea surface temperature).