Technical challenges of coupled land-atmosphere data assimilation for operational Numerical Weather Prediction and reanalyses

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Toward coupled assimilation in ECMWF’s operational systems

- **Consistency** of the coupling approaches across the different components of the Earth System
- **Modularity** to account for the different components in coupled assimilation
- **Common infrastructure** for land, atmosphere, ocean, sea ice, waves for NWP and reanalysis

Earth system approach

Integrated Forecasting System (IFS)
Current operational NWP system at ECMWF

Weakly coupled land-atmosphere-wave and sea ice assimilation

Plans to develop land-atmosphere coupling at the outer-loop level of the atmospheric 4D-Var
Coupled assimilation in operational systems

Methodology:
• Coupled assimilation challenges, coupling strategy from weak to strong coupling, etc
• Link to methodology and unified framework development (e.g. OOPS at ECMWF)

Infrastructure:
• Earth System approach → consistent & modular suite definition for land and atmosphere, use same file system for all components,
• Develop/maintain consistent research offline and coupled, and operational coupled tools

Observing system and monitoring:
• Access to observations, common acquisition for land & atmosphere, observation pre-processing, quality control, data selection, feedback files, monitoring, auto-alert system, ...

Observation operators:
• Coupling for observations that depend on more than one sub-system (e.g. low frequency MW observations sensitive to the surface), explore AI/ML approaches
Observing system: the example of in situ snow depth

Near-Real-Time access to observations

SYNOP TAC SYNOP BUFR national BUFR data

Snow depth availability o the Global Telecommunication System (GTS)

15 January 2015
Observing system: the example of in situ snow depth

Near-Real-Time access to observations

SYNOP TAC SYNOP BUFR national BUFR data

15 January 2021

Snow depth availability on the Global Telecommunication System (GTS)

Ongoing/near future: improvement in the US (NOAA)
Snow data exchange and WMO

- Global Cryosphere Watch (GCW) and Snow Watch Team
  → snow data exchange WMO regulation, **BUFR template** (with Observation Team), link to GODEX

- SG-CRYO and JET-EOSDE (both WMO Infrastructure Commission) → relevant for coupled assimilation
ECMWF Soil Analysis for NWP

Ensemble Data Assimilation (EDA)

NWP Forecast Coupled Land-Atmosphere

EDA Jacobians

T2m, RH2m & soil moisture Background

Screen level analysis (2D-OI)

T_2m RH_2m

\[ \sigma^o_{T2m} = 2K \quad \sigma^o_{RH2m} = 10\% \]

Soil Analysis (SEKF)

SM1, SM2, SM3

\[ \sigma_{O_{T2M}} = 1K \quad \sigma_b = 0.01m^3/m^3 \quad \sigma_{SMOS_{NN}} = 0.02+3\epsilon \]

\[ \sigma_{O_{RH2M}} = 4\% \quad \sigma_{ASCAT} = 0.05m^3/m^3 \]

Land initial conditions

SMOS Neural network

SMOS TB

Simplified Extended Kalman Filter (SEKF) with EDA Jacobians
Uncouped Land surface analysis systems

→ Support research and land surface reanalysis

1. Offline surface model forced by atmospheric reanalysis (e.g. ERA5-land)
   😊 Allows enhanced surface model/resolution
   ☹ No land DA

2. Offline soil moisture DA (Rodriguez-Fernandez et al, 2019)
   😊 As (1), but offline soil moisture analysis included
   ☹ A priori observation processing and gridding
   ☹ No snow DA

3. Stand-alone surface analysis (SSA, Fairbairn et al., 2019)
   😊 Full land DA system in IFS (soil moisture, snow, etc...)
   😊 Coupled land-atmosphere model
   😊 Same observation interface than NWP
   😊 No atmosphere DA so cheaper than coupled DA system
   ☹ Still significantly more computationally expensive than (1) and (2)

Fairbairn et al., 2019 *J. Hydrometeor*, 2019. [https://doi.org/10.1175/JHM-D-19-0074.1](https://doi.org/10.1175/JHM-D-19-0074.1)
Observation monitoring and quality control

SMOS brightness temperature operational monitoring

• Summer 2020: a large area of RFI (Radio Frequency Interference) contamination over South-East China
• Improved screening does a better job of filtering it out but still not perfect
  – Need for further improvements in RFI filtering flags
  – Importance of quality control

![Basic RFI screening](image1)

![Stronger RFI screening](image2)
New observation implementation

SMAP monitoring (May 2021)

- Set-up operational NRT acquisition
- Scripts suite and prepIFS changes complete
- SMAP Observation interface (Obs Data base, ODB)
- Script and Fortran changes
- Suite definition and prepIFS
- Monitoring webpage update

→ Full chain of developments to integrate new observations in a complex (Earth) system
Coupling through the observation operator

- New interface between CMEM (surface) and RTTOV (atmosphere) radiative transfer schemes
- Multi-layer snow radiative transfer scheme (HUT, Lemmetyinen et al., 2010) in CMEM offline
- **Adapt to model cycle changes, take advantage to improve coupled DA**

Use the multi-layer snowpack model (Arduini et al JAMES 2019) to assess the impact of multi-layer approach on snow emissions against AMSR2 10GHz data

Multi-layer snowpack scheme leads to reduce STDV and gives higher correlation values between ECMWF forward and AMSR2 observed brightness temperatures at 10GHz

Hirahara et al., 2020
[https://doi.org/10.3390/rs12182946](https://doi.org/10.3390/rs12182946)

--- Single Layer
--- Multi-layer snowpack and RT
--- Multi-layer snowpack only
SMOS neural network soil moisture assimilation

Rodriguez-Fernandez et al., HESS 2017, RS 2019

A priori training of the SMOS neural network processor
-> retraining when L1Tb or IFS soil change
Online training possibilities?

Further explore ML/AI for forward modelling
Summary

model cycle
modularity
data acquisition
feedback file
operations
online training
offline
monitoring
observing system
data format
data exchange
outer-loop coupling
near real time
sustainability
archiving
auto-alert system
consistency
NWP
data selection
weak coupling
research
suite definition
seamless
observation interface
quality control
research