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Current Status and Future Plans for KIM Land Surface Data Assimilation

Diagnosis and evaluation team

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Introduction to Korean Integrated Model (KIM)

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- KIAPS was founded in 2011 by Korea Meteorological Administration to develop Korea's own global NWP system.
- KIM, the result of KIAPS phase 1 project, has been run in the operation at KMA since 2020.
- The new KIAPS phase 2 project (2021 to 2026) has begun to further upgrades to the core system; km-scale NWP; extension of forecast range to monthly timescales; and expansion from atmosphere-only to coupled system.

KIM

- Is a global atmospheric model which **has a spectral-element nonhydrostatic dynamical core on a cubed sphere grid** (Hong et al., 2018).
- Its horizontal and vertical resolutions are 12km and 91 layers (hybrid sigma-pressure coordinate), in the operational run.
- KIM utilizes **a hybrid four-dimensional variational data assimilation (4DEnVar) for deterministic and Local Ensemble Transform Kalman Filter (LETKF) for ensemble to correct atmospheric initial conditions** (Kwon et al., 2018).
- With the real-time observations processed by **KIM Package for Observation Processing** (KPOP, Kang et al., 2018).

History of KIM Global Land Data assimilation System

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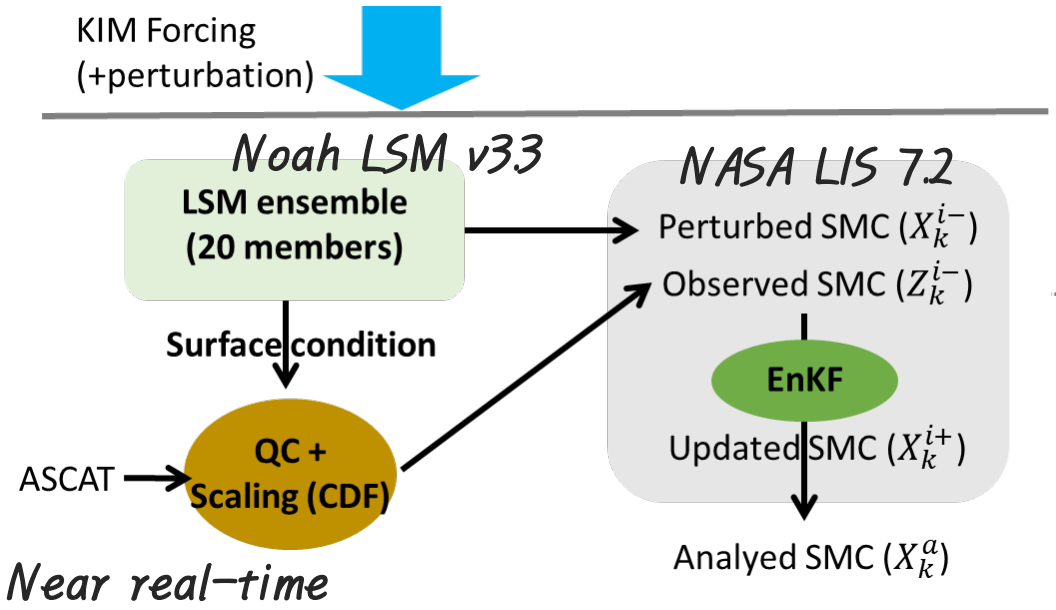
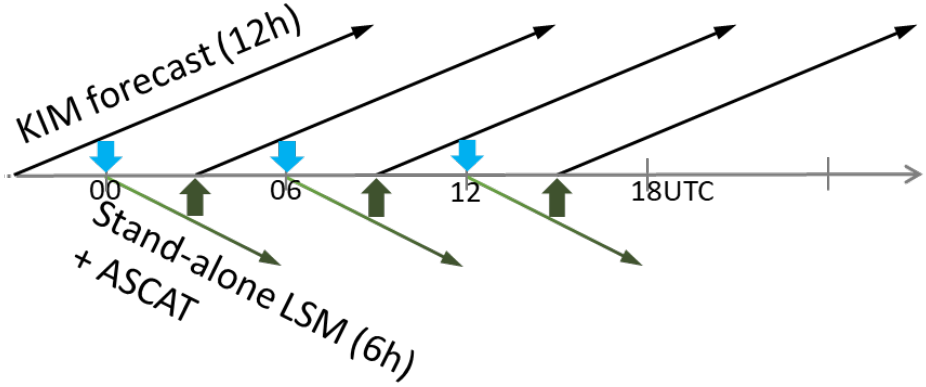
- Not only atmospheric initial conditions but also land surface initial conditions are needed to be corrected by real-time observations.
- Thus, land data assimilation system has been developed and run operationally to initialize soil moisture and snow for KIM at KMA.

KIM Version	Variable	Observation	Methods
3.6 (Oct. 2020)	• Soil moisture	• Metop-A,B ASCAT	• EnKF
3.6a (Apr. 2021)	• Snow	• IMS	• Obs Oper.
3.7 (Dec. 2021)	• Snow for ensemble • Soil moisture	• IMS • Metop-B,C ASCAT	• From KIM deterministic

Soil moisture data assimilation system for KIM

- Atmospheric perturbations and soil moisture perturbations are added to run **stand-alone LSM ensembles**.
- **ASCAT observations** in near-real time are processed through quality controls and scaling using CDF matching method.
- **EnKF updates LSM soil moisture to scaled ASCAT observation** so that produce analyzed soil moisture, which initialize land surface condition of KIM every 6-hours.
- **This system is based on NASA LIS (Kumar et al., 2006; Peters-Lidard et al., 2007), but the frame work should be replaced by KIM frame work because of native grid and program consistency.**





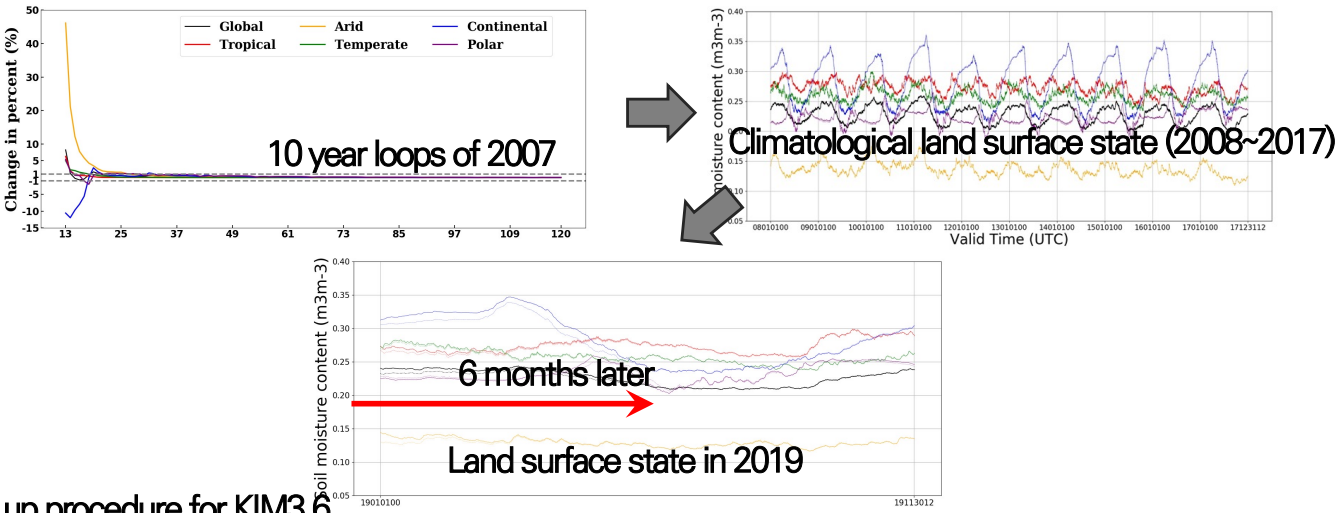
Jun et al., 2021

Spin-up of off-line LSM

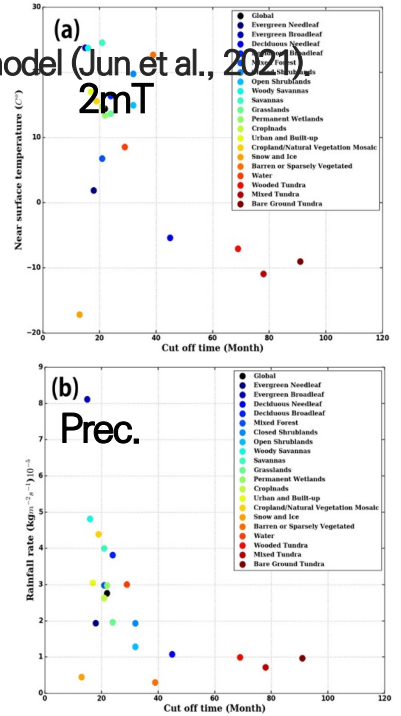
To produce initial land surface condition,

- In a previous study, LSM reached to the equilibrium state of soil moisture through repeatedly 10 year loops (Jun et al., 2020).
- For KIM3.6, LSM initial condition was obtained by additional 6 month spinning up LSM after climatological land state (2008 to 2017).
- Spin-up time for the equilibrium condition of soil moisture indicated inverse correlation with T & Prec.
- **However, this analysis focused on the 1st layer, but root zone (3rd) layer is also important to even NWP model (Jun et al., 2021).**
- **Thus, further spin-up studies are needed to obtain proper land initialization.**

Soil moisture at 1st layer



Spinning up procedure for KIM3.6



Spin-up time

Jun et al., 2020

ASCAT soil moisture (H SAF, 2019)

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ASCAT soil moisture

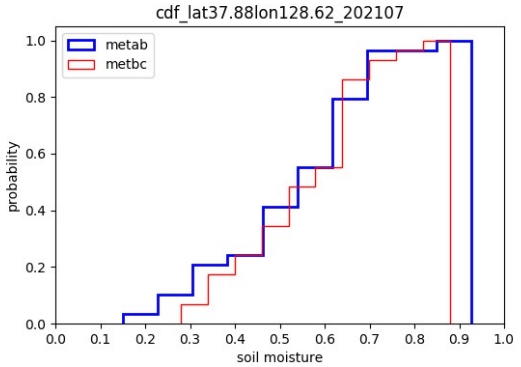
- Active, microwave C-band measurement, where the addition of liquid water to soil increases backscatter.
- It is delivered timely and stably for NWP model in real time.

Quality control

- Errors (16%), Wetland (15%), Topology (20%), Greenness (70%), Freezing Temp., Rainfall, Snow water Equiv., MODIS IGBP (1~4, forest)

MetOp-A has been replaced by MetOp-C in operational run.

- Metop-A (2006.10-2021.12), Metop-B (2012.09-), Metop-C (2018.11-)
- MetOp B and C have similar statistical distributions with MetOp A and C

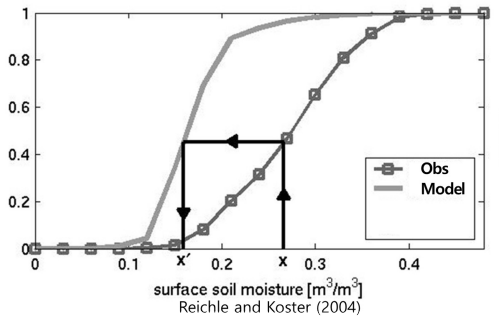


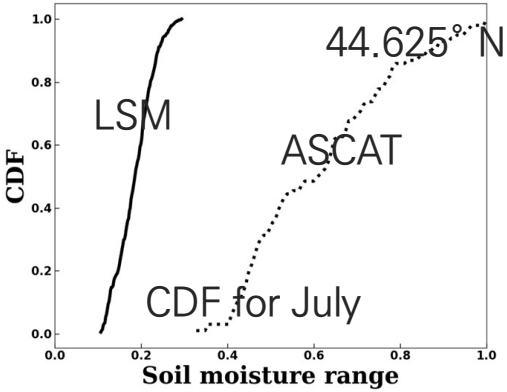
Satellite	Frequency	Resolution	Algorithm
Metop-A, B, C	C-band(5.255GHz)	12.5km	Wagner et al. (2011)

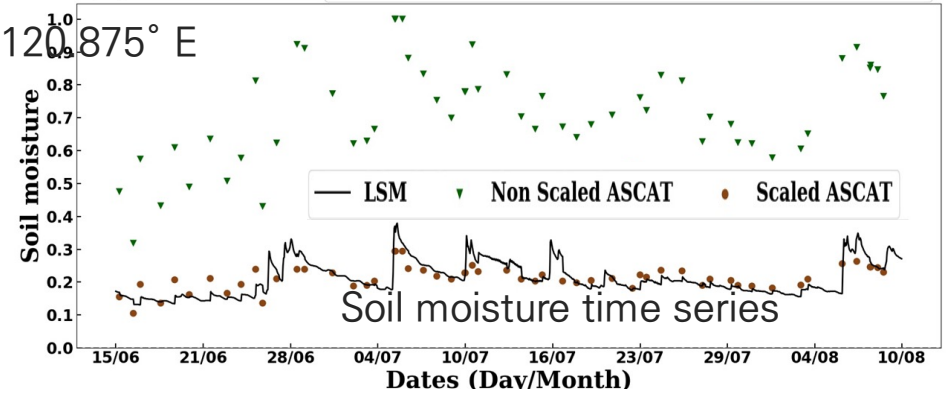
Cumulative Density Function (CDF) matching

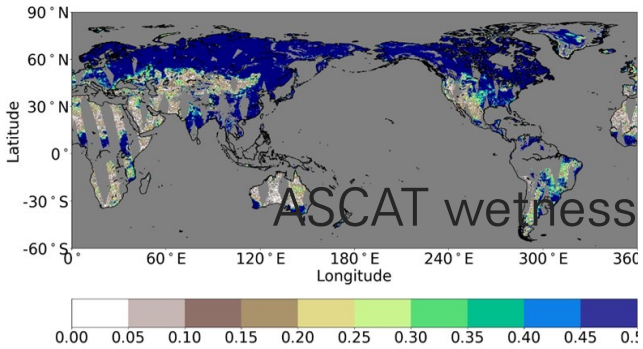
The CDF matching

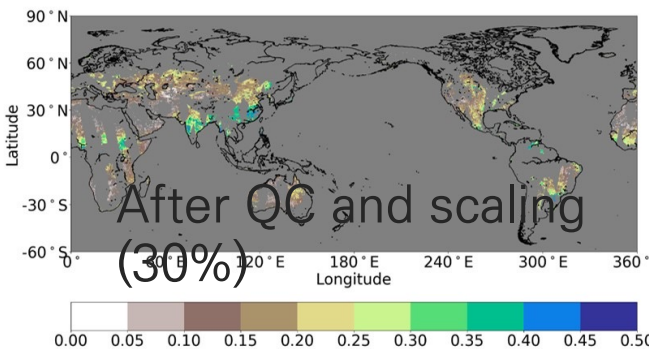
- is to match the CDF of the ASCAT soil wetness to the CDF of the model's volumetric soil moisture.
- To correct observation biases before assimilation and convert wetness to volumetric (LSM climate)
- **Additional satellite observations are needed because the amount of ASCAT data after QC is 30% against before.**

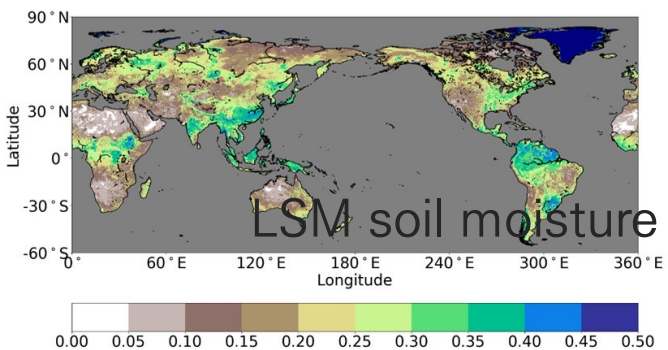








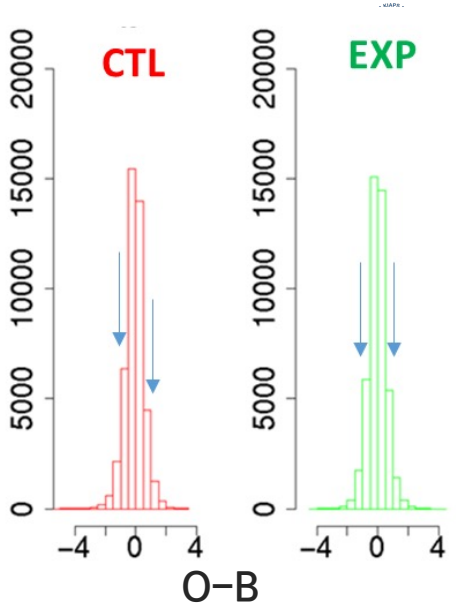




Proper CDF for KIM land surface states

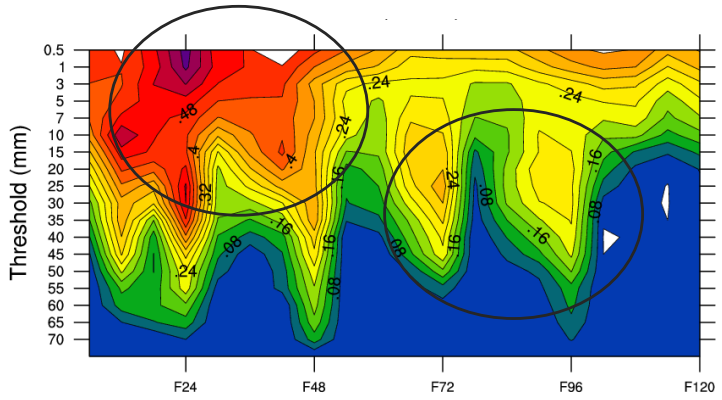
Preliminary results of a replacing CDF experiment

- **(EXP)** CDF with KIM forcing and **(CTL)** with GLDAS forcing
- EXP reduces dry biases of observation increments.
- And improves forecast skill and especially in precipitation at South Korea.
- **This indicates observation operator should be developed to fit in KIM**

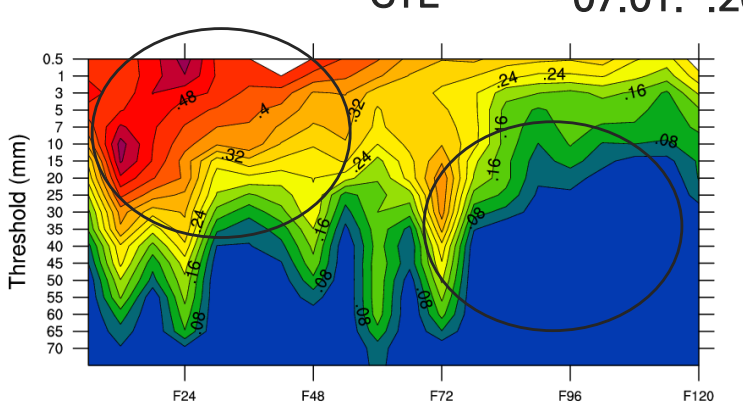


ETS

EXP



CTL 07.01.~.26.

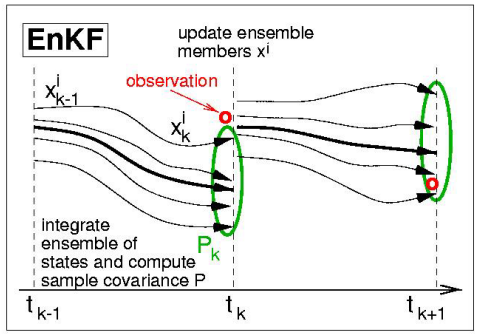


Ensemble Kalman Filter (EnKF)

EnKF

$$x_t^{i+} = x_t^{i-} + K_t\left[z_t - Hx_t^{i-}\right]$$

- Kalman filter updates model state with an observation based on the uncertainty information, referred to as the error covariance and is estimated from an ensemble model at the time when EnKF is updated.
- EnKF requires observation and model background to be gaussian distributed and unbiased to each other. Thus, we applied CDF matching to bias-correction.
- 1-D EnKF induces two main problems (Reichle et al., 2003; Han et al., 2015).
  - There is no consideration for spatial correlations of land surface and atmospheric forcing
  - We cannot update model grid cells with no observations.
- 3-D EnKF or LETKF strategies can be undertaken.



(Reichle et al., 2002)

Perturbations

- Perturbations are applied to atmospheric forcing and land surface states, indicating the uncertainty of forcing and LSM's physics and parameters.
- The nonlinear feature of this perturbation process can make the ensemble background biased, thus unintended perturbation biases are corrected using an unperturbed member.

N. ensemble	Method/Variables	Bias Correction
20	Multiplicative (SW, PREC) Additive (Model SMC, LW)	Ryu et al. (2009)

Soil moisture assimilation effects on KIM

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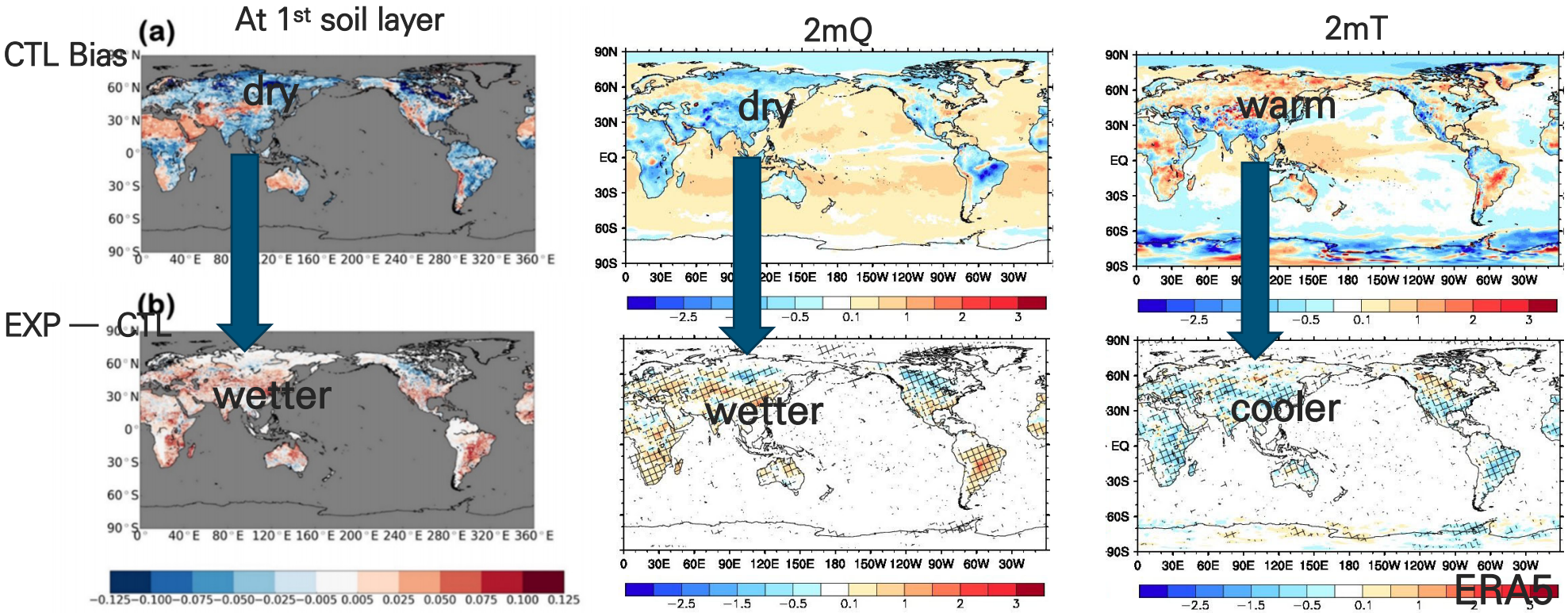
Analysis field changes in land surface and screen level

T+0D (Boreal summer)

- CTL was drier than ERA5, except for arid areas, but the EXP* was wetter than the CTL in most regions.
- EXP reduces dry and warm biases, which are dominant in the CTL in screen level.

* with Soil moisture assimilation

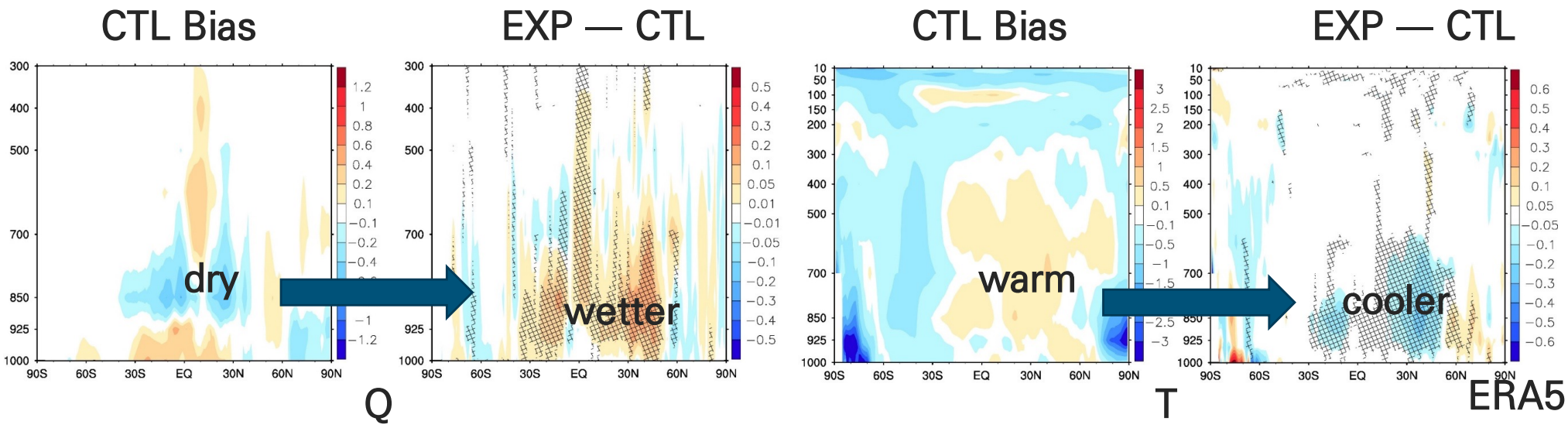


Soil moisture assimilation effects on KIM

Forecast changes in the vertical cross section of Q and T

- CTL indicated drier and warmer than ERA5 in the lower and mid atmospheric levels in lower latitude.
- EXP lessened the dry biases and warm biases.
- Changes in near surface fluxes are conveyed into upper atmosphere.

T+5D (Boreal summer)



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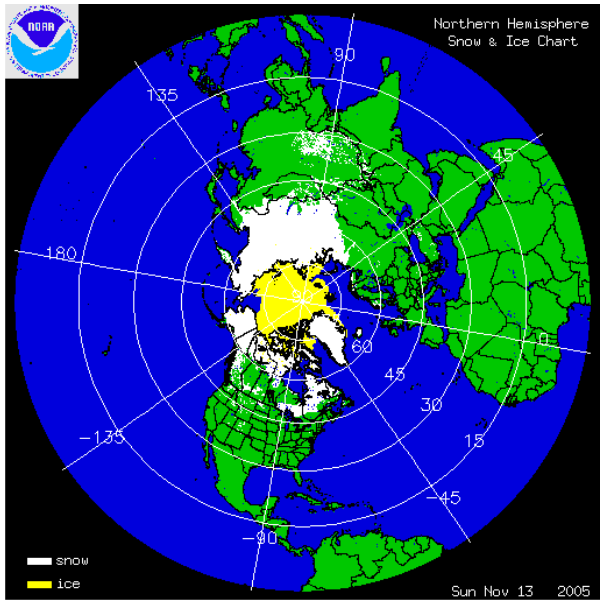
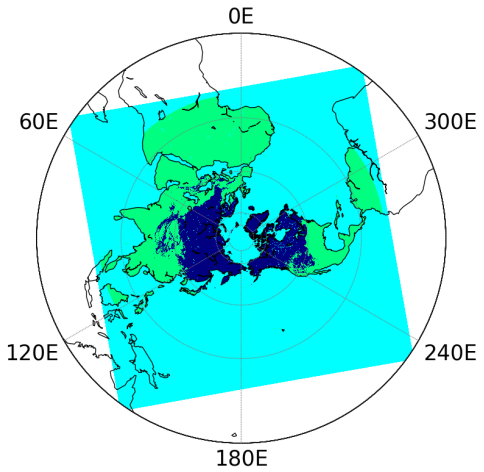
IMS snow cover by NOAA/NESDIS

Interactive Multisensor Snow and Ice Mapping System (IMS)

- IMS consists of multi-satellites & ground observations to produce snow cover information in all weather conditions.
- The IMS product is available daily for the northern hemisphere.
- The product is used as an operational input into several NWP models.

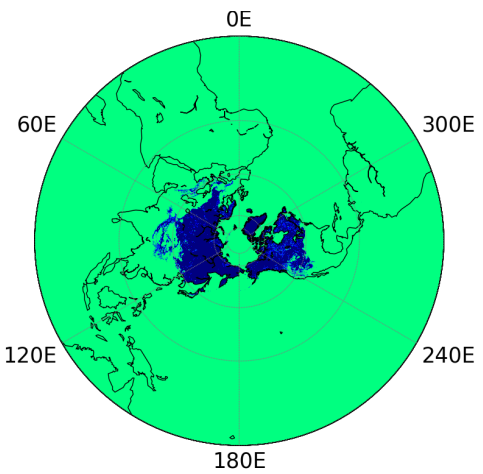


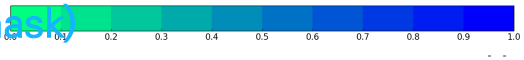
Helfrich et al., 2018



IMS snow cover raw data
Blue (100%); Green (0%); Sky (mask)

IMS snow fraction (0~1)





Snow data assimilation method

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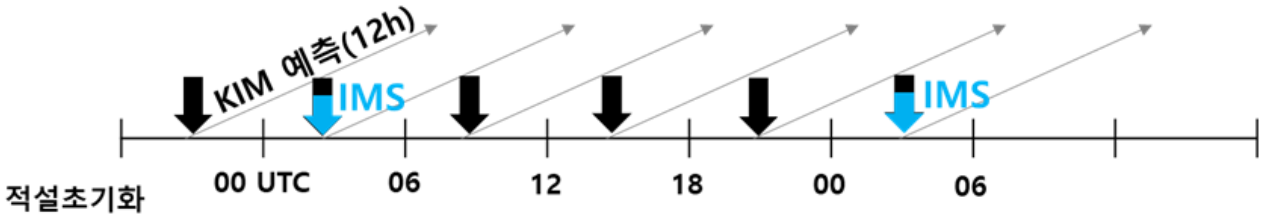
Step 1. correcting first guess for SWE using IMS data

- When snow exists in both IMS and previous cycle background, leave background unchanged.
- When snow exists in IMS but there is no snow in previous cycle background, set SWE in model background.
- When IMS snow cover is zero, previous day background is not zero, set analysis to zero.
- When IMS snow cover is zero, previous day background is zero, trust model background and leave analysis unchanged.

observation \ model		snow	Snow free
		Previous cycle (T−6H)	
snow	1	–	10
	0~1		$-\log(1-SC)\times 5(\leq 10)$
Snow free		Previous day (T−1D)	
		0	–



Correcting snow pack background using IMS snow cover

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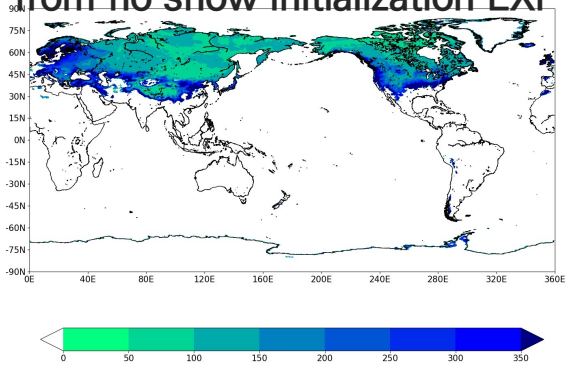
Step 2. calculating snow depth using snow water equivalent

$$Snow\ depth\ (m) = \frac{snow\ water\ equivalent\ (kgm^{-2} - 2)}{snow\ density\ (100kgm^{-3})}$$

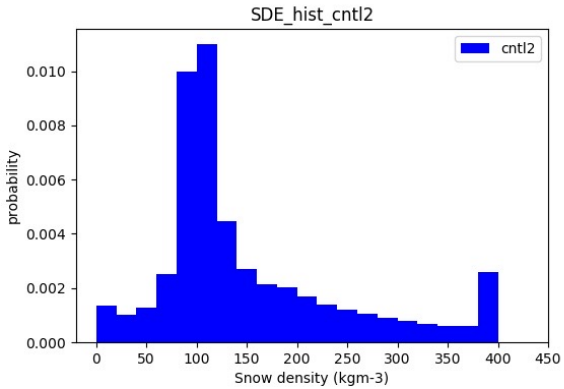
KIM Snow density (2020.1.1~10) from no snow initialization EXP



Snow density

- Constant for snow density ($100kgm^{-3}$).
- However, KIM indicated 0~400 kgm^{-3} snow density range.
- Thus, KIM-LSM new snowfall density equation could be applied for consistency.
- Also, actual snow amount observations (ground or satellite) should be used for initializing SWE or SD

$$\mathrm{sndens} = 0.05 + 0.0017\times(2\mathrm{mT}-273.15+15.)\times1.5$$



Snow data assimilation effects on KIM

* Snow assimilation

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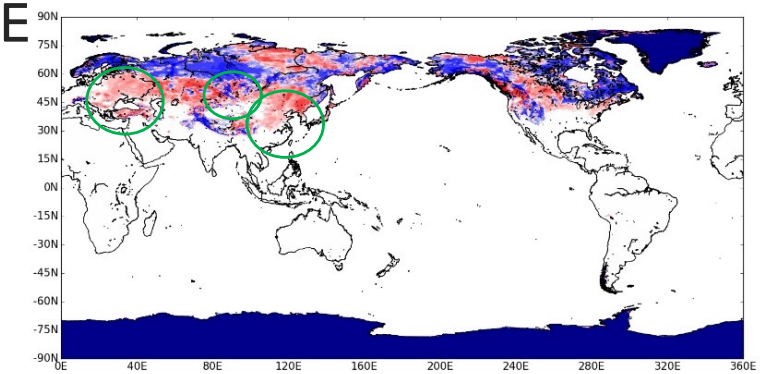
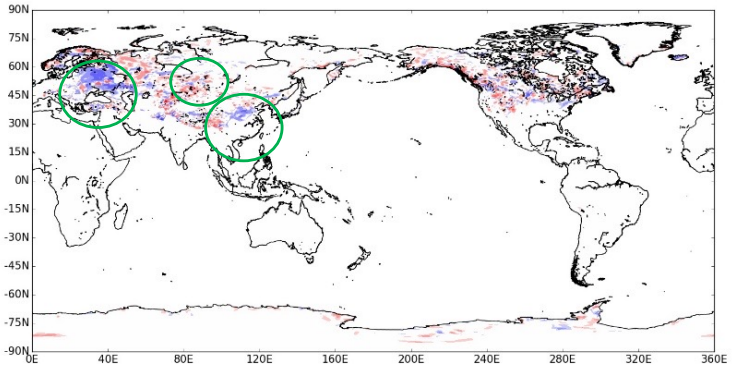
CTL Bias

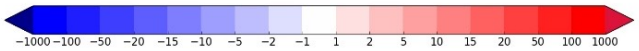
T+0D (Boreal winter)

EXP* — CTL

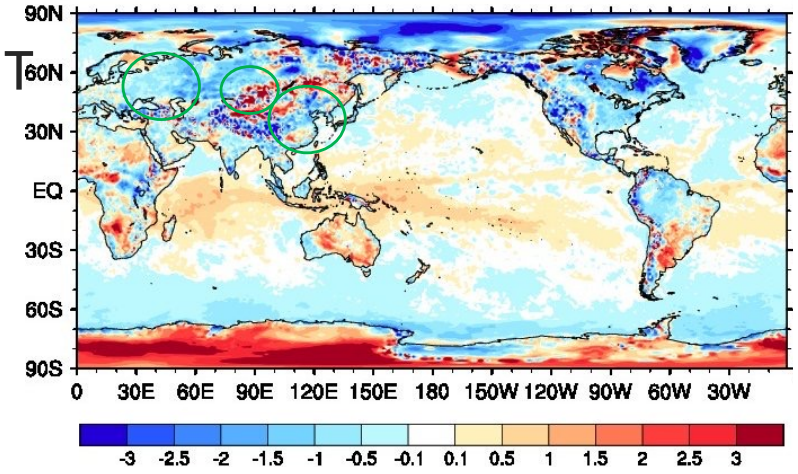
SWE

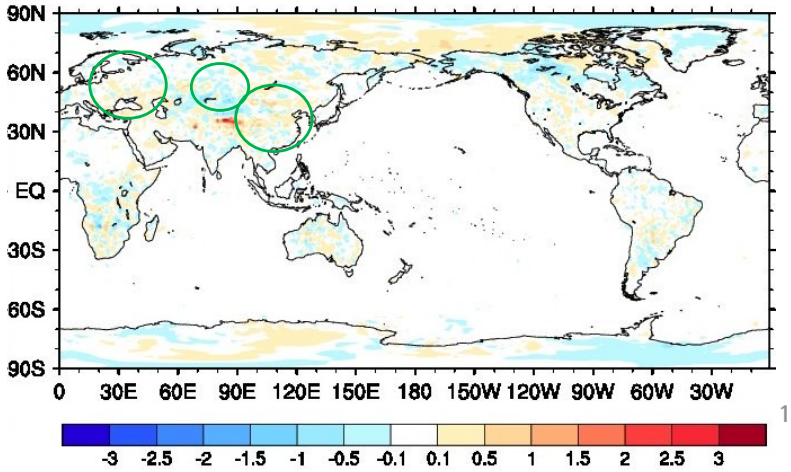






2m T





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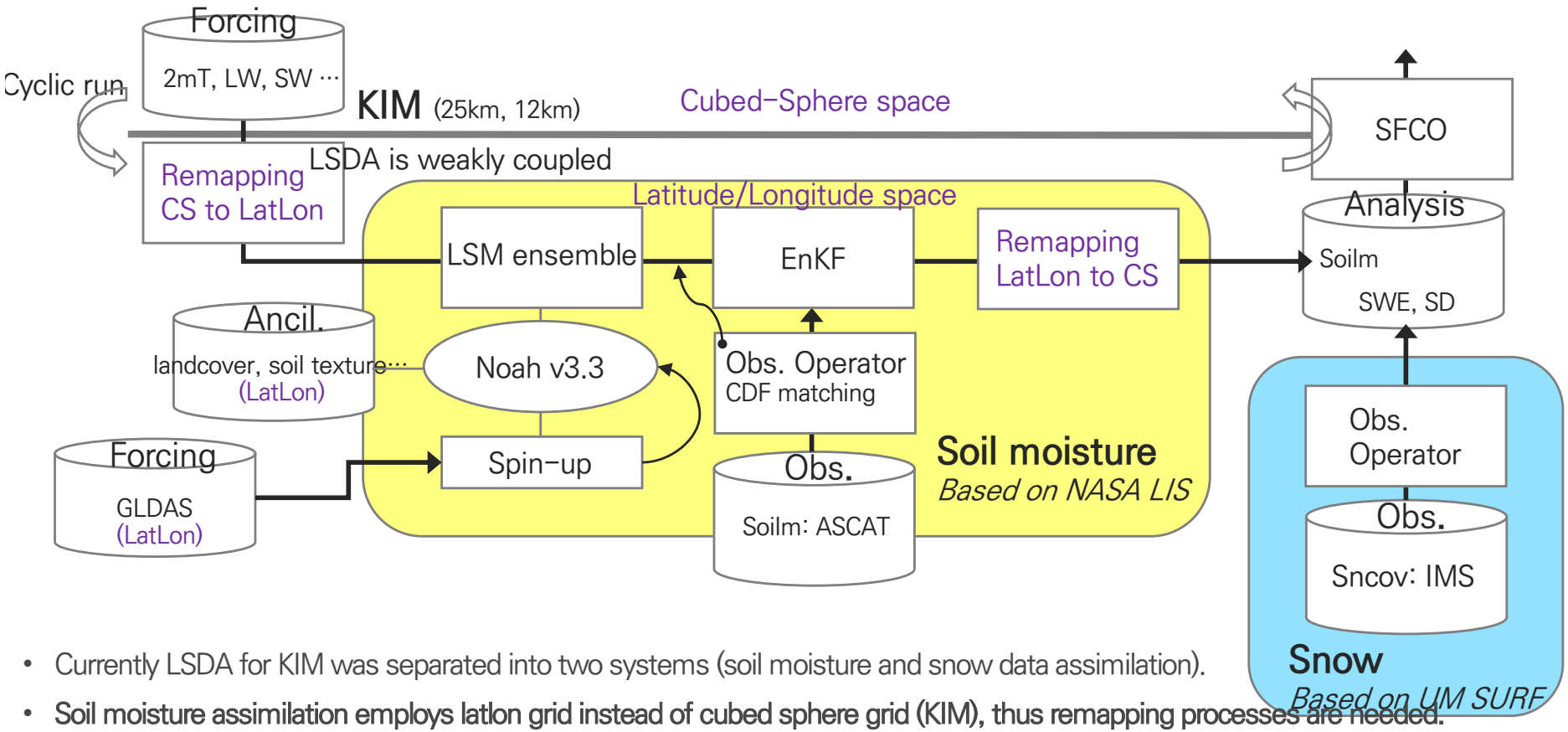
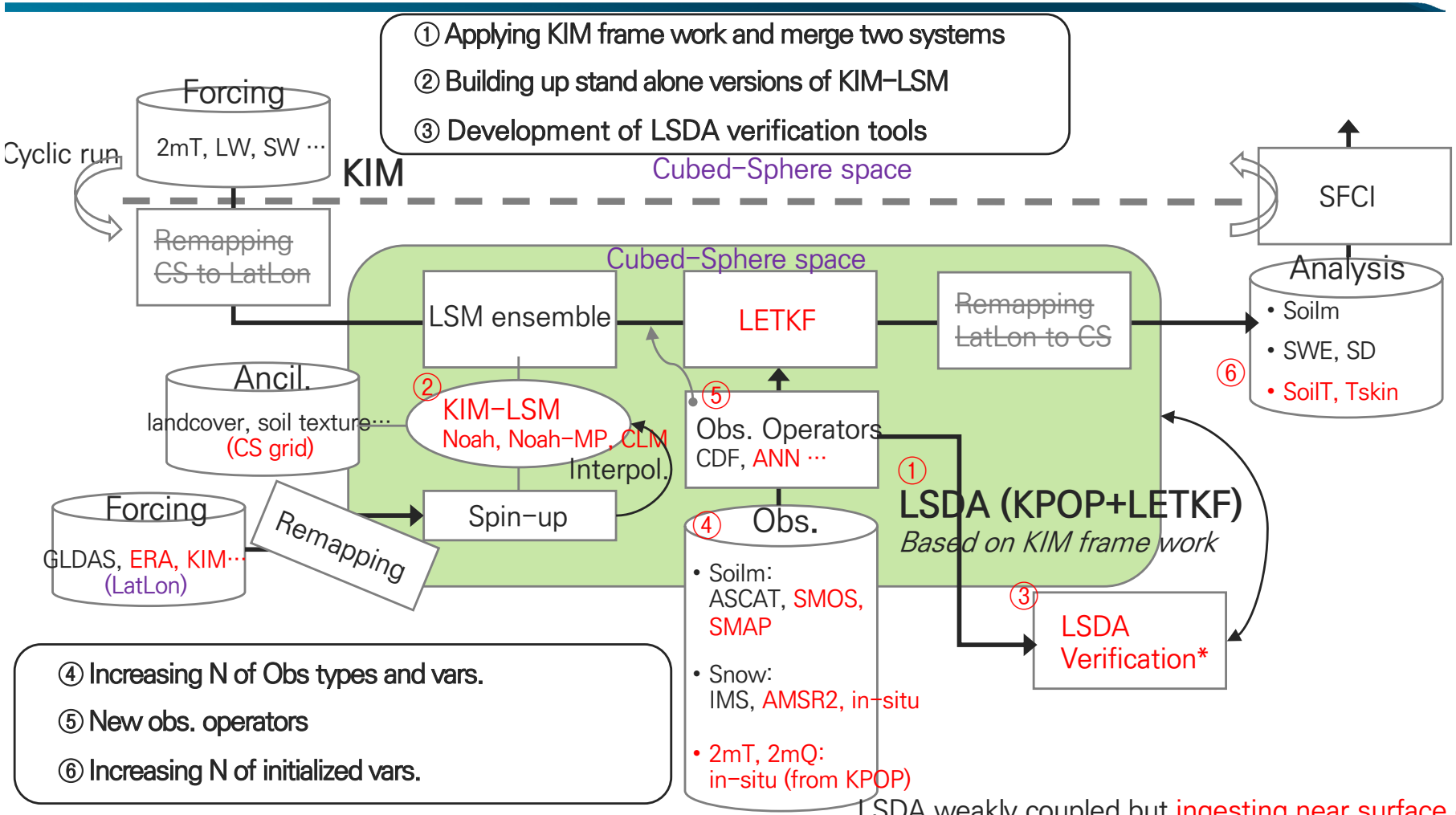
Current frame work



- Currently LSDA for KIM was separated into two systems (soil moisture and snow data assimilation).
- **Soil moisture assimilation employs latlon grid instead of cubed sphere grid (KIM), thus remapping processes are needed.**
- Also, Noah LSM v3.3 is used for soil moisture assimilation, which might simulate different land surface fluxes with KIM-LSM.

New frame work suggested for KIM LSDA



LSDA weakly coupled but ingesting near surface observations.

New frame work suggested for KIM LSDA

① Applying KIM frame work and merge two systems

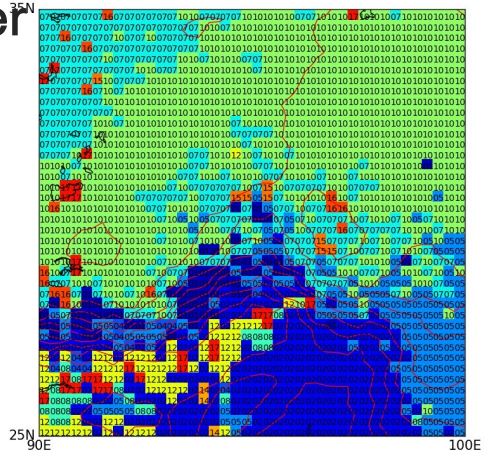
- By adopting KIM native grid (CS grid), KIM LSDA overcome information losses of remapping processes (latlon to CS, land's highly heterogeneous characteristics in space)
- Can easily change in KIM horizonal resolution (100km, 25km 12km, 8km), but still interpolation module should be used for land initial condition and climatology from spinning-up.

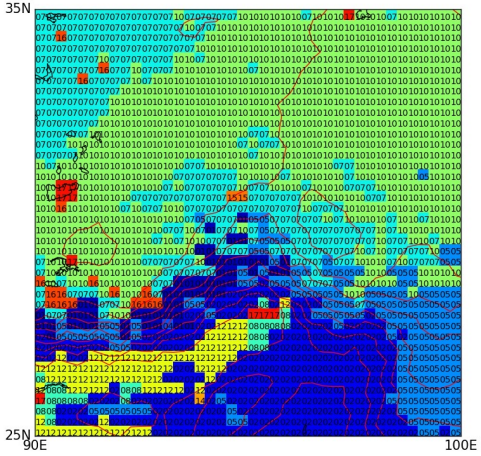
Land cover

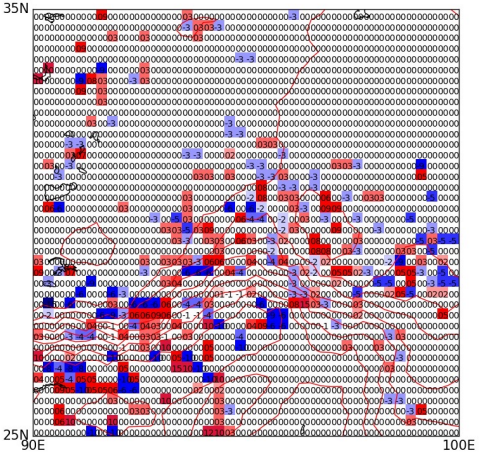
LatLon

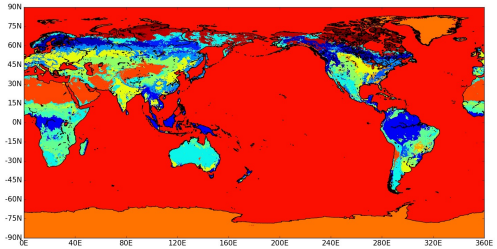
CS

Diff









- Evergreen Needleaf
- Evergreen Broadleaf
- Deciduous Needleaf
- Deciduous Broadleaf
- Mixed Forest
- Closed Shrublands
- Open Shrublands
- Woody Savannas
- Savannas
- Grasslands
- Permanent Wetlands
- Croplnads
- Urban and Built-up
- Cropland/Natural Vegetation Mosaic
- Snow and Ice
- Barren or Sparsely Vegetated
- Water
- Wooded Tundra
- Mixed Tundra

New frame work suggested for KIM LSDA

① Applying KIM frame work and merge two systems

- Instead of LIS frame work, KIM DA system will be employed for preprocess of observations and data assimilation.
- The frame work consistency between KIM atmospheric DA and LSDA will be achieved.
- Limitations (spatial correlations) of 1-D EnKF can be overcome by employing LETKF, which provides the computational benefits.

KPOP frame

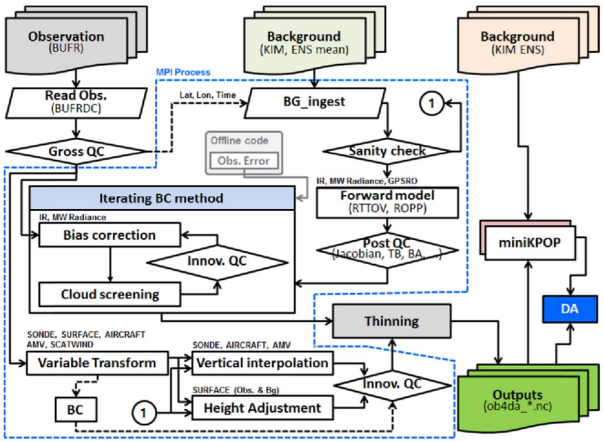


Fig. A1. Block diagram of the KIAPS package for observation processing (KPOP) designed to provide qualified observations for the data assimilation system.

Kang et al., 2018

KIM 4DEnVar

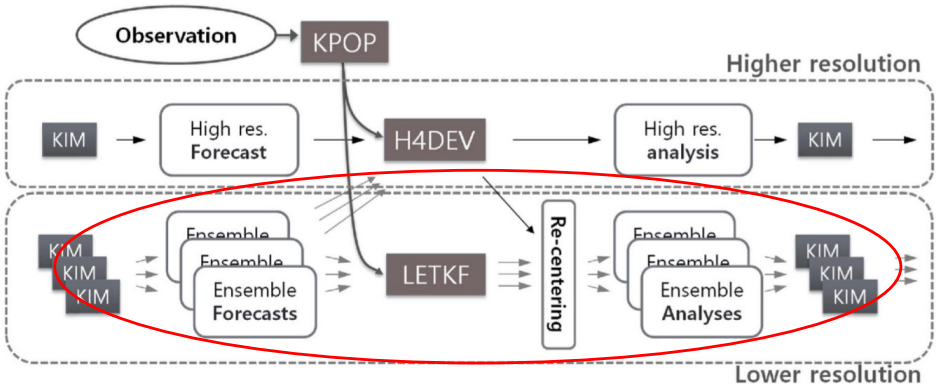


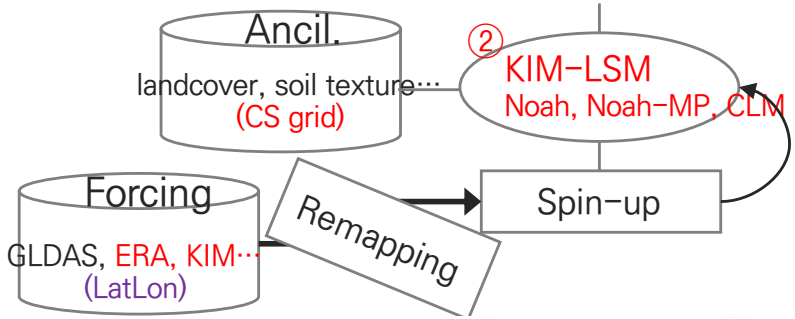
Fig. 1. Flow chart of the hybrid H4DEV analysis cycle system. The KPOP processes observations for both H4DEV and LETKF, and the recentering replaces the ensemble mean analysis with deterministic analysis. Presently, the high-resolution and low-resolution are respectively 12 km and 50 km horizontally, and the ensemble size is 50 members.

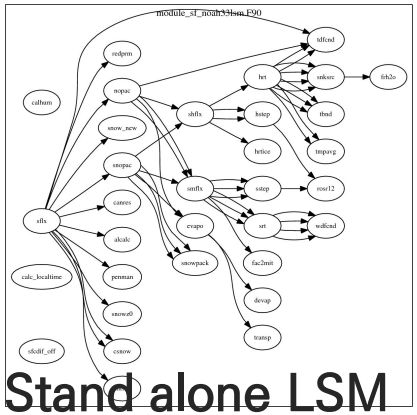
Kwon et al., 2018

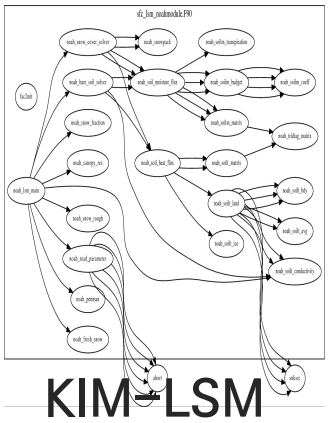
New frame work suggested for KIM LSDA

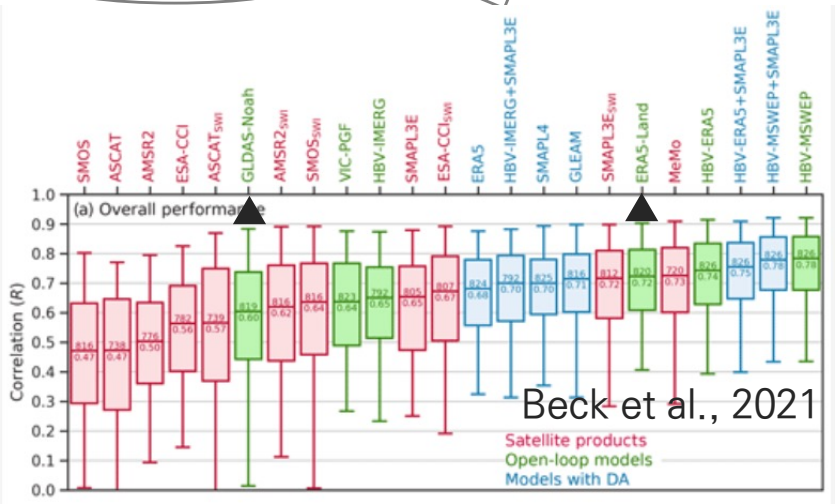
② Building up stand alone versions of KIM-LSM

- A stand alone KIM-LSM will be built-up for land data assimilation and model development.
- There are three candidates (Noah, Noah-MP, CLM) for next generation KIM-LSM.
- Data assimilation system will be set up for a next generation KIM-LSM.
- Also, spinning-up will be carried out to provide land initial conditions and climatology used for LSDA.
- For spinning-up, ERA5 and KIM could be an appropriate candidate.




Stand alone LSM


KIM-LSM



New frame work suggested for KIM LSDA

③ Development of LSDA verification tools

- LSDA verification tools will be developed based on NASA LVT.
- First of all, **in situ observations such as soil moisture and snow depth will be used for LSDA verification.**
- This tools will be continuously modified to apply new observations that will be added in the LSDA system.

International Soil Moisture Network Locations

(Dorigo et al., 2021)

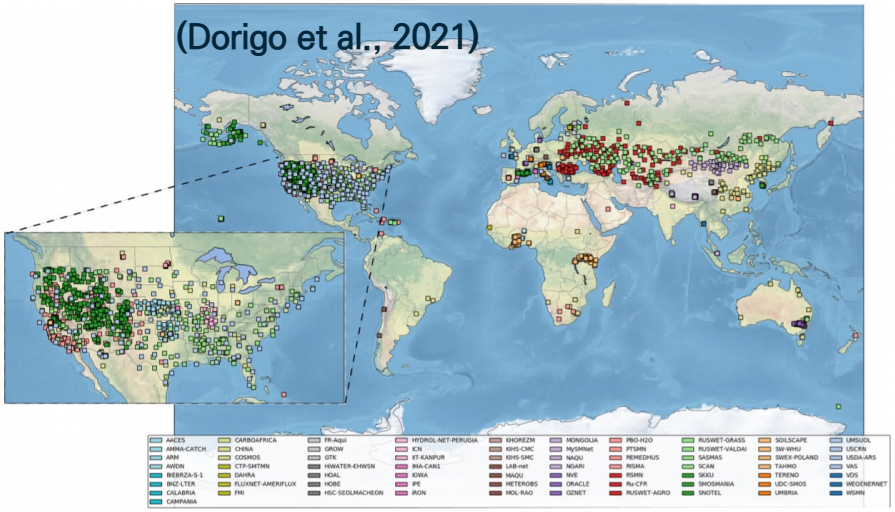
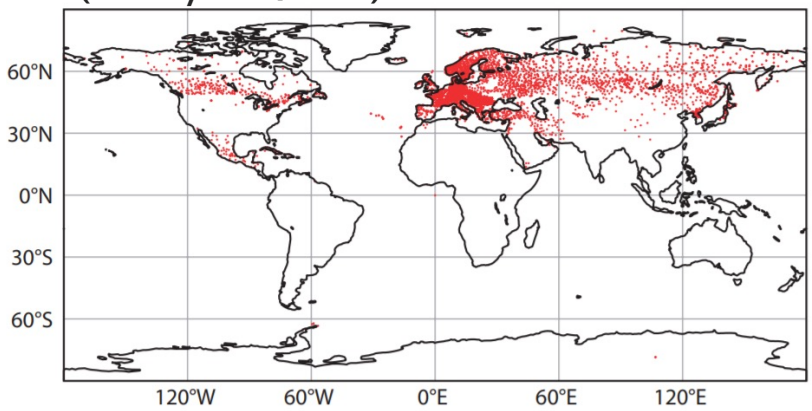


Figure 1. Locations of ISMN networks and sites plotted with the ISMN package described in the code and data availability section (status in July 2021).

In situ spatial distribution for snow depth

(Rosnay et al. 2015)

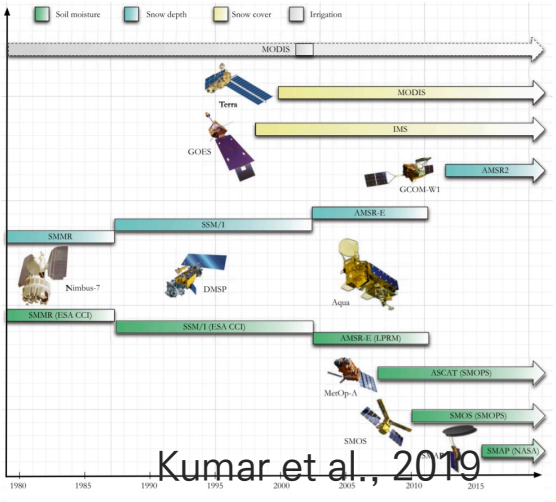


New frame work suggested for KIM LSDA

KIAPS

④ Increasing the number of observation types and variables.

- **Soil Moisture and Ocean Salinity (SMOS) and Soil Moisture Active Passive (SMAP), two passive microwave sensors** will be included in addition to ASCAT, an active sensor for soil moisture assimilation.
- Currently, not actual snow pack observations snow cover observations are used for SWE and SD initialization.
- **Thus, in-situ snow depth observations will be used for snow assimilation.**
- Plus, **satellite snow water equivalent products or Tbs could be assimilated using EnKF.**
- **Screen level observations such as 2mT and 2mQ from KPOP will be employed for LSDA, so that LSDA could be closer to atmo-DA,**
  and it is possible to add new initialized variables.



Kumar et al., 2019

④ Obs.

- Soilm:
  ASCAT, SMOS, SMAP, in-situ
- Snow:
  IMS, AMSR2, in-situ
- 2mT, 2mQ:
  in-situ (from KPOP)

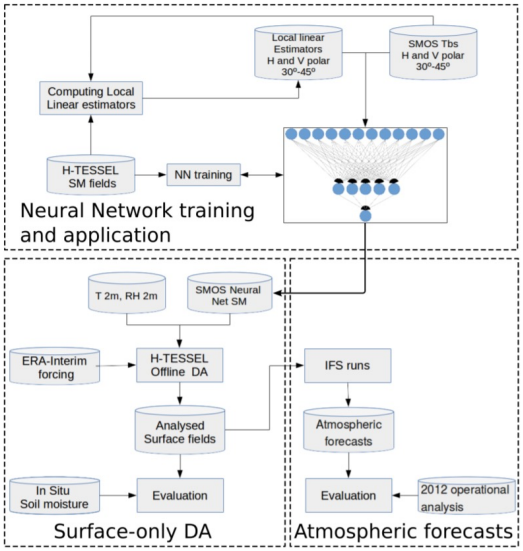
⑥ Analysis

- Soilm
- SWE, SD
- SoilT, Tskin

New frame work suggested for KIM LSDA

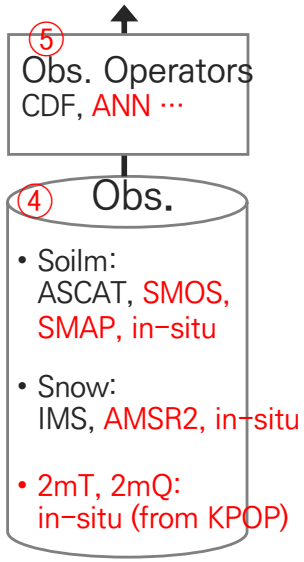
⑤ New observation operators

- Increasing observation types demands **development of observation operators fit in an individual observation and KIM-LSM.**
- For example, an observation operator using Artificial Neural Network have been used to estimate soil moisture from SMOS for real-time soil moisture assimilation in ECMWF.
- No need to additional scaling process for this estimation because ANN provides data which is similar to model and has no biases against model.



igure 1. Flow chart of the neural network data assimilation and evaluation methodology.

Rodríguez-Fernándezr et al., 2019



Summary

KIAPS

Current status

- KIM land surface data assimilations has been developed and run operationally since Oct. 2020.
- **Soil moisture system based on NASA LIS** assimilates ASCAT soil moisture using EnKF.
- **Snow system based on UM SURF** corrects background snow amount using IMS snow cover.

Future plans

- **The new LSDA system will adopts KIM frame work.** It makes LSDA frame work more flexible to changes of horizonal resolution in KIM, prevents information losses from remapping, and provides program consistency and computational benefits.
- Also, a stand alone **KIM-LSM** will be inserted into LSDA. Data assimilation modules for a next generation KIM-LSM will be set up.
- Evaluation tools for LSDA will be developed using ground observations.
- **New types and variables of observations and their observation operators** will be added such as SMOS and SMAP soil moisture, in-situ snow depth, screen level temperature and humidity. This screen level observations will make it possible to **initialize soil temperature and skin temperature**.

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Thank you