Snow depth and snow cover over the Tibetan Plateau: evaluation of global reanalyses using in-situ observations and satellite remote sensing products

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Motivation

- ❑ Due to its spatial extent, high elevation and geographical position in the mid-latitudes, the TP exerts a considerable influence on regional and global climate (e.g., East Asian and Indian monsoons) [Wu et al., 2012, 2015; Xiao and Duan, 2016]

- ❑ The extent and variability of the snowpack over the TP has been a major research focus because of the role of snow radiative, hydrological or thermodynamical feedbacks impacting:
  - ➢ the surface energy balance
  - ➢ the hydrological cycle
  - ➢ the large-scale circulation

- ❑ This high-elevation snowpack is distinctly shallow, patchy and short-lived

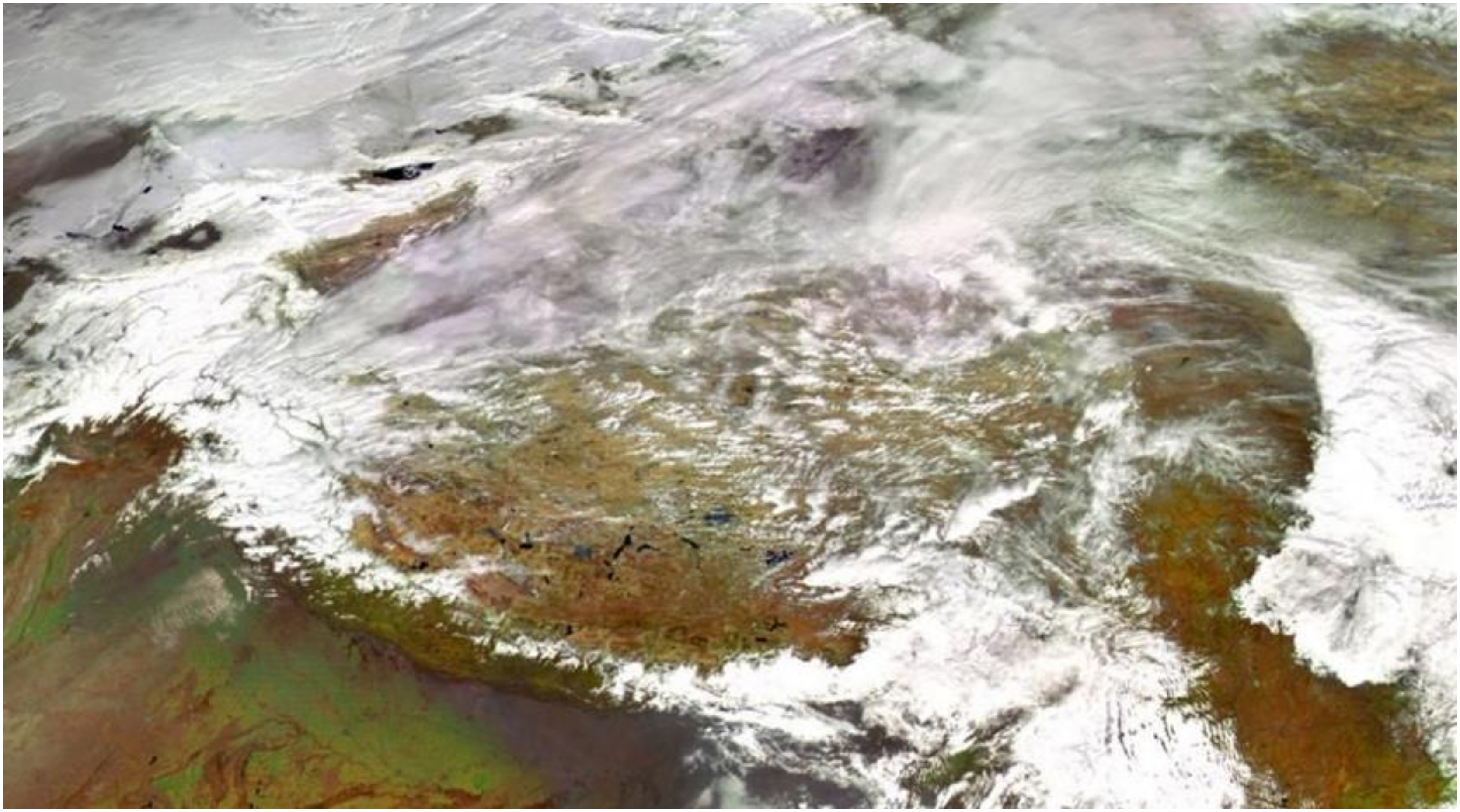
- ❑ Many studies analysed snow remote sensing products over the TP (e.g., MODIS, IMS, …). [Basang D. et al., 2018; Yang et al., 2015; Li W. et al. 2018]

- ❑ No study yet has aimed at systematically evaluating snow depth or cover in the <u>re-analyses</u>, against in-situ data and remote sensing products

- ❑ Yet, re-analyses are widely used in climate research and long-range forecasting

The Tibetan Plateau and surrounding regions were formally proposed as the Third Pole by Nature in 2008.

Image of the Tibetan Plateau from the Chinese geostationary meteorological satellite FY4



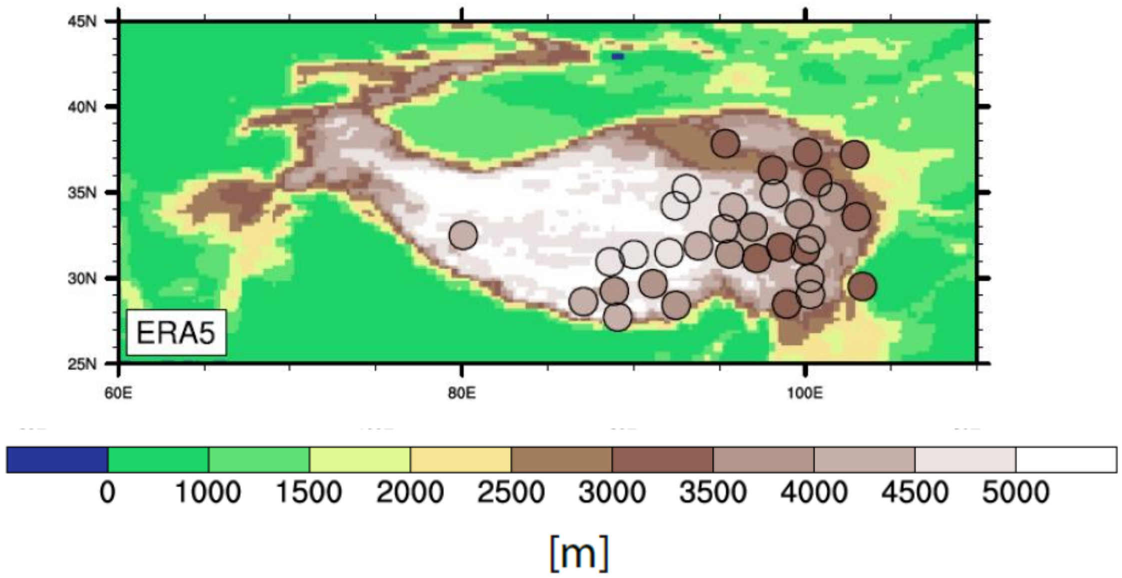
Even in mid-winter, large areas of the TP can be void of snow

(source NSMC, CMA)

20 February 2017

In-Situ station observations over the TP

- **CMA (China Meteorological Administration) station data**
  - **Five years : 2009-2013**
  - **Daily snow cover and depth, min and max air temperature (*Ta*), daily precipitation**
  - **33 stations on the TP, but most of the stations are located in inhabited valleys, below 4000m, in the southeastern part**



Topography

Issues with representativeness of in-situ data

❑ for the TP as a whole, due to sparseness in western part

❑ local conditions in a complex terrain

Inter-comparison of 4 re-analyses with in-situ data and satellite products

- We compare in-situ data with 4 recent re-analyses:

- (New) ERA-5 (ECMWF)
- (older) ERA-Interim (ECMWF)
- JRA-55 (JMA)
- MERRA-2 (NASA)

- With satellite products :
- snow cover from NOAA IMS blended product (multi-instrument incorporating visible, IR, microwave satellite data, in-situ) [4 km, regridded to 25 km]
- snow depth (microwave satellite) from CAREERI Institute (Langzhou, China) over 2009-2010

(CAREERI: Cold & Arid Regions Environmental & Engineering Research Institute)

ECMWF family (ERA-Int, ERA5)

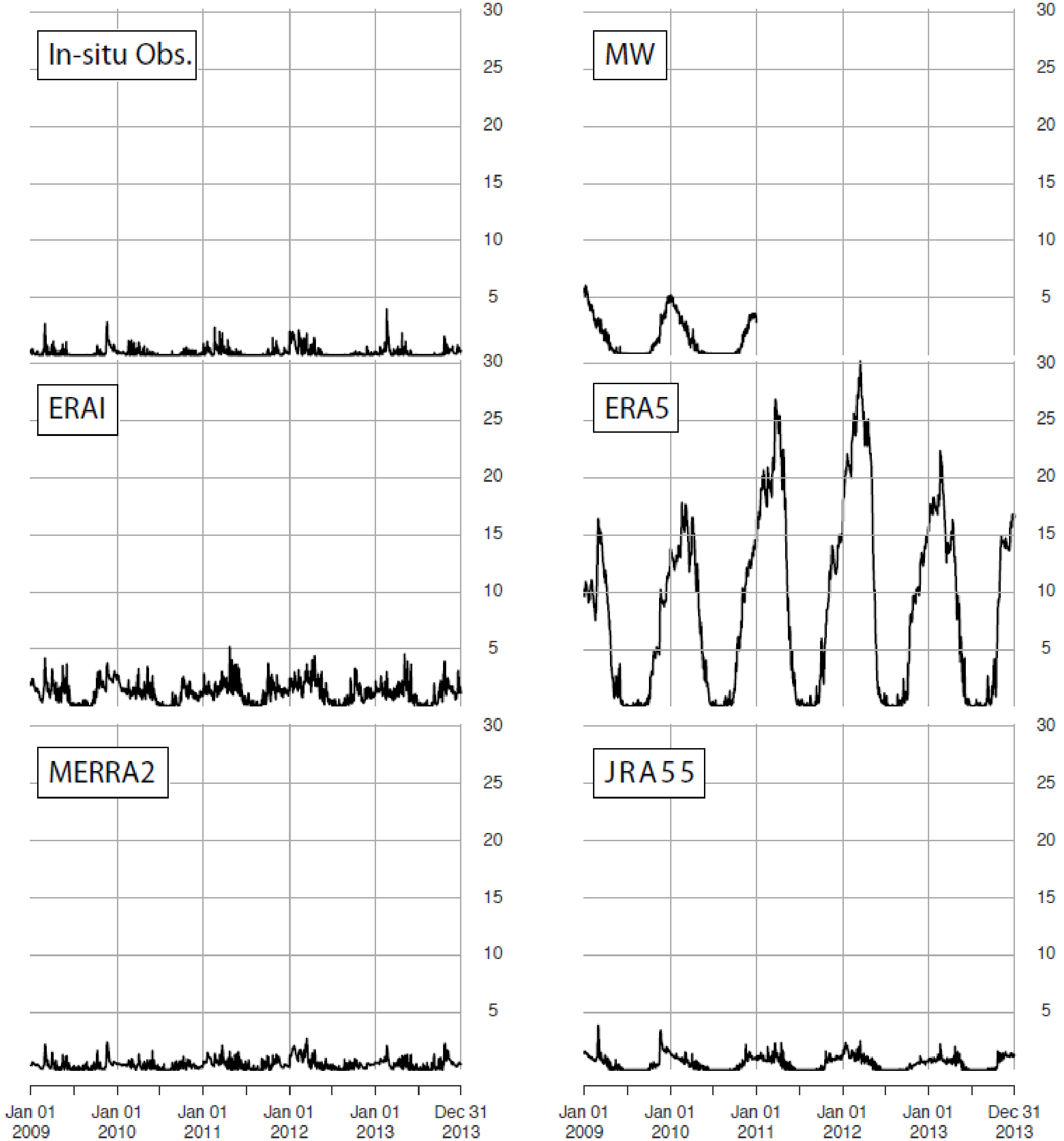
	ERA-Int	ERA5	MERRA-2	JRA-55
Approximate Spatial resolution	~79km	~31km	~50km	~55km
Land Model version	TESSEL	HTESSEL	Catchment LSM	SIB
Atmospheric Model	IFS Cy31r2	IFS Cy41r2	GEOS 5.12.4	JMA GSM
Assimilated snow data	In-situ (but not on TP), IMS snow cover (24 km)	In-situ (but not on TP), IMS snow cover (4 km) but not at high altitude above 1500m	NONE	In-situ (also on TP), MW (SSM-I, SSMIS) snow cover
Snow model	1-layer	1-layer	3-layer	1-layer

Comparison of daily snow depth (SD) at the stations

period 2009-2013
average over 33 stations
Unit : 0-30 cm

Observations:
In-situ

Observations:
Microwave satellite



ERA-Interim (<u>older</u>)
ECMWF

ERA5 (<u>newest</u>)
ECMWF

Difference: assimilation of satellite snow cover at high altitude (incl. over TP)

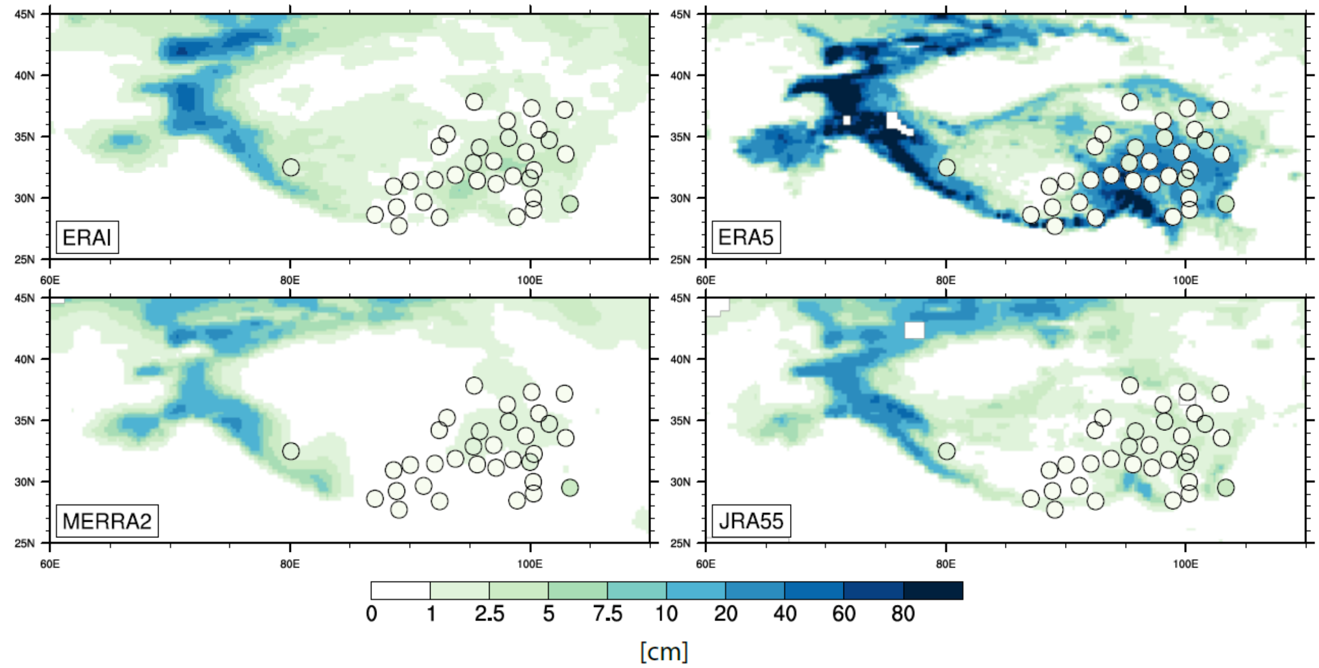
MERRA-2
NASA, USA

JRA-55
JMA, Japan

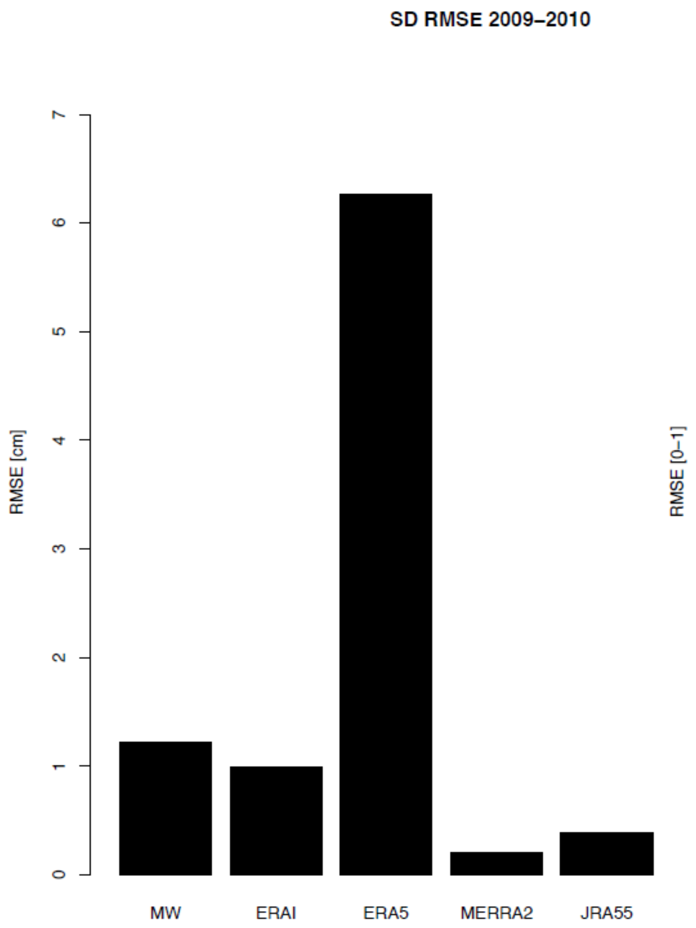
Some re-analyses largely overestimate SD over the TP, compared to in-situ data

Maps of snow depth

(JAN mean, over 5 years)



- **Overestimation of SD in some reanalyses compared to in-situ data**
- **MERRA-2, followed by JRA-55, have best performance (RMSE)**



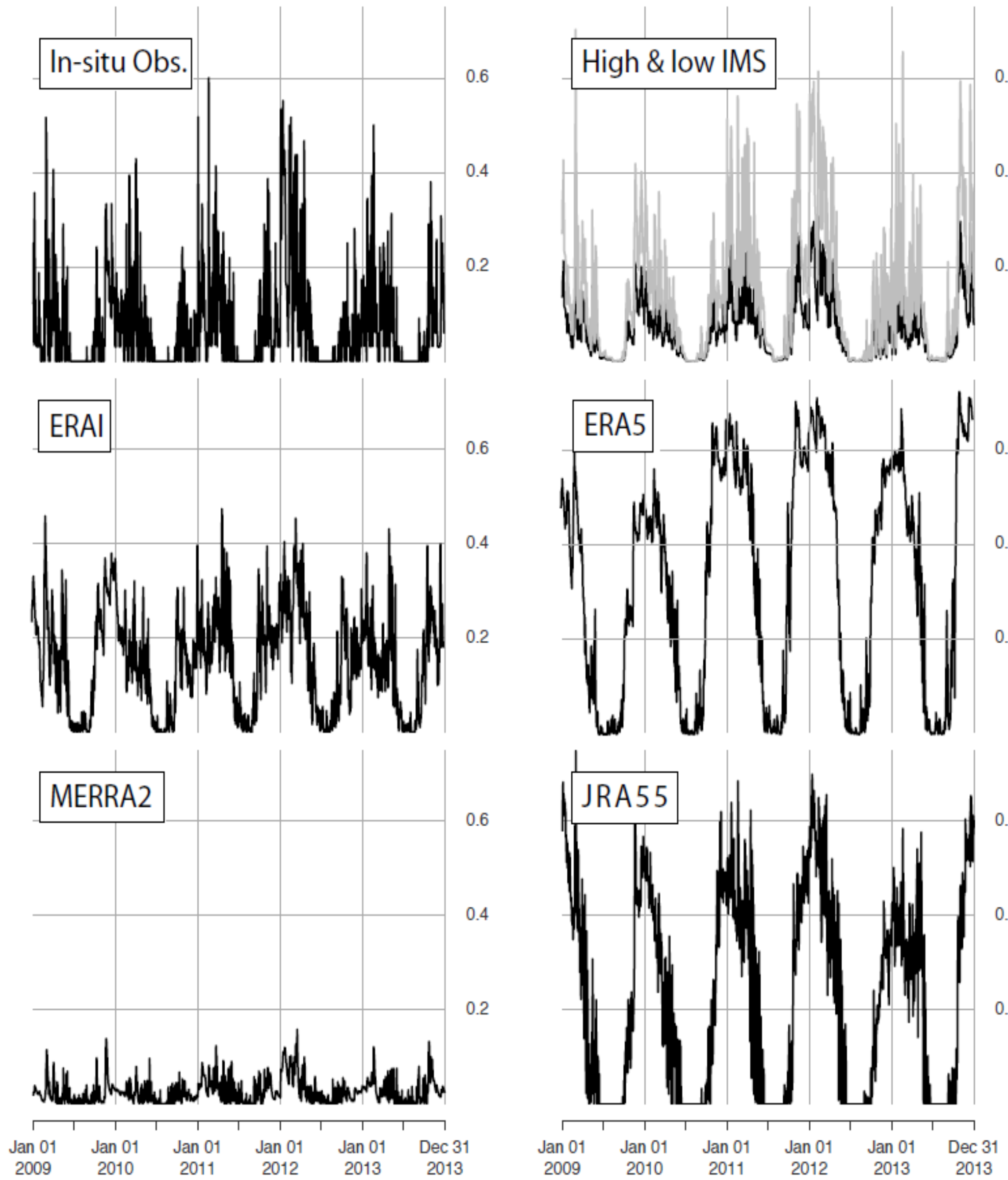
RMSE

(year-round, over 2009-2010)

Comparison of daily snow cover fraction (SCF) at the stations

Observations:
In-situ

Observations:
IMS product
(high and low estimates
due to pixel conversion)



ERA-Interim (older)
ECMWF

ERA-5 (newest)
ECMWF

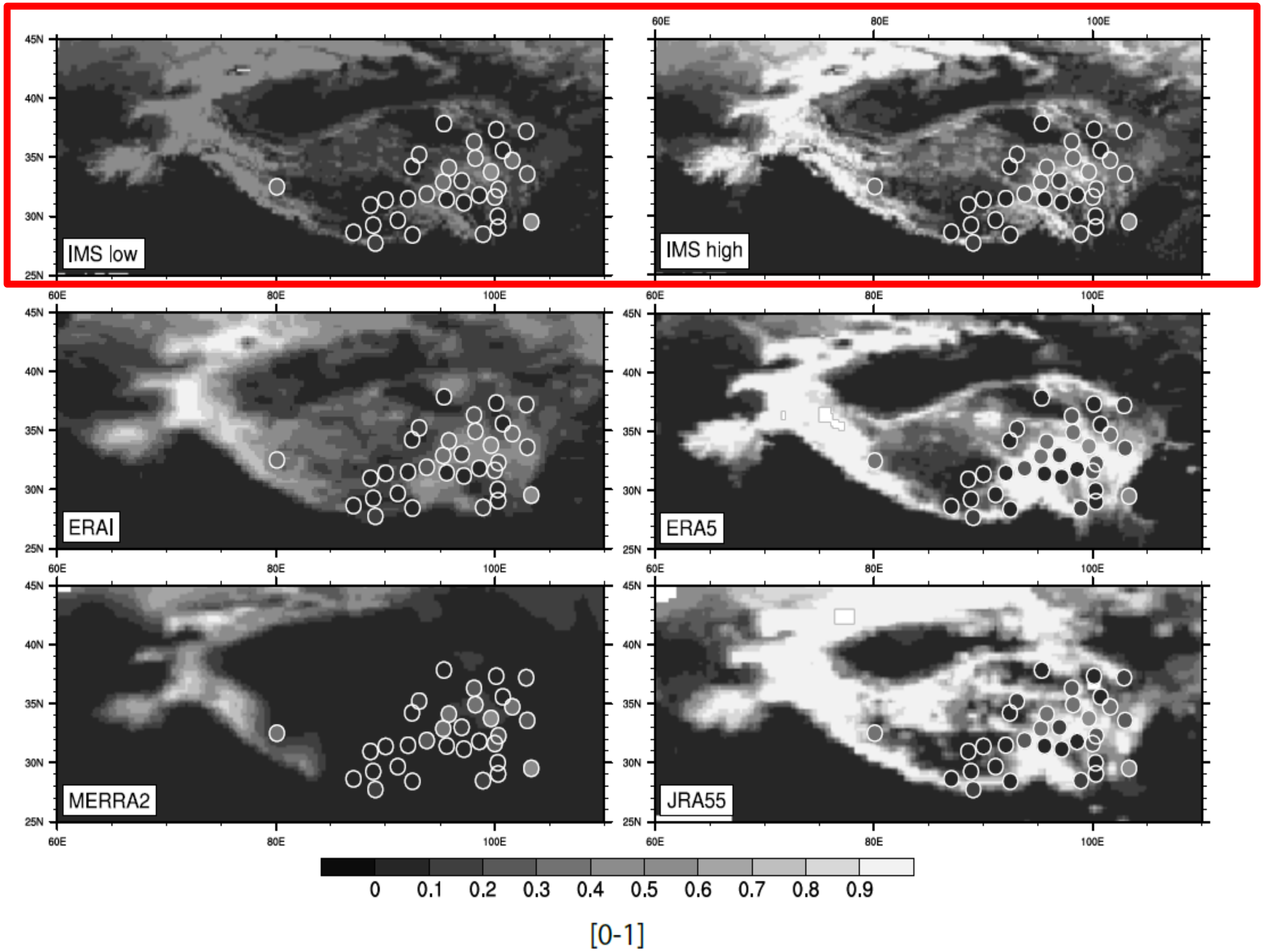
MERRA-2
NASA, USA

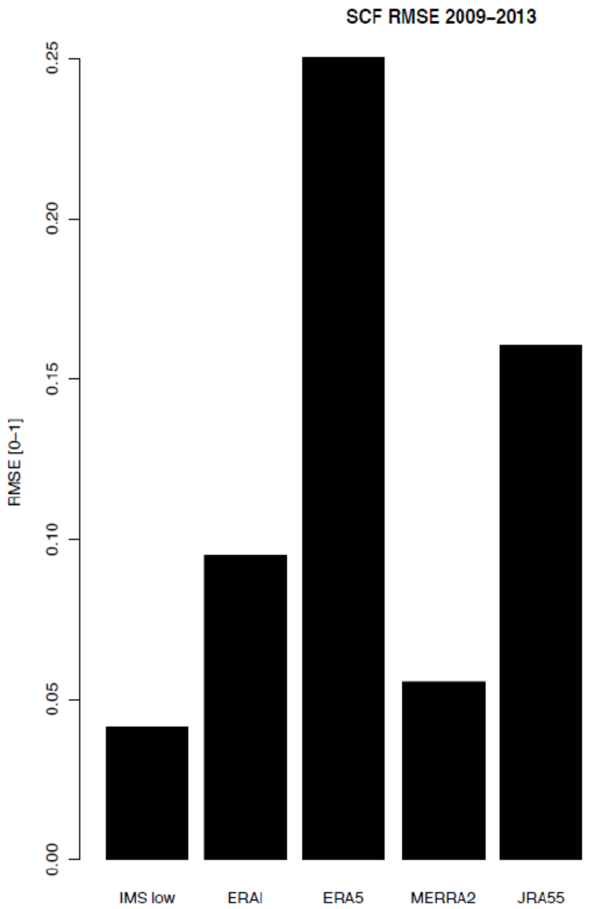
JRA-55
JMA, Japan

period 2009-2013
average over the 33 stations

Maps of snow cover fraction in re-analysis, satellite and in-situ data (JAN mean – 5 years)

- Good agreement between in-situ station data and IMS
- ECMWF family : over-estimation by ERA5
- JRA-55 has not best performance for SCF as for SD (consistently too high)





Monthly-mean annual cycle at stations

period 2009-2013
average over the 33 stations

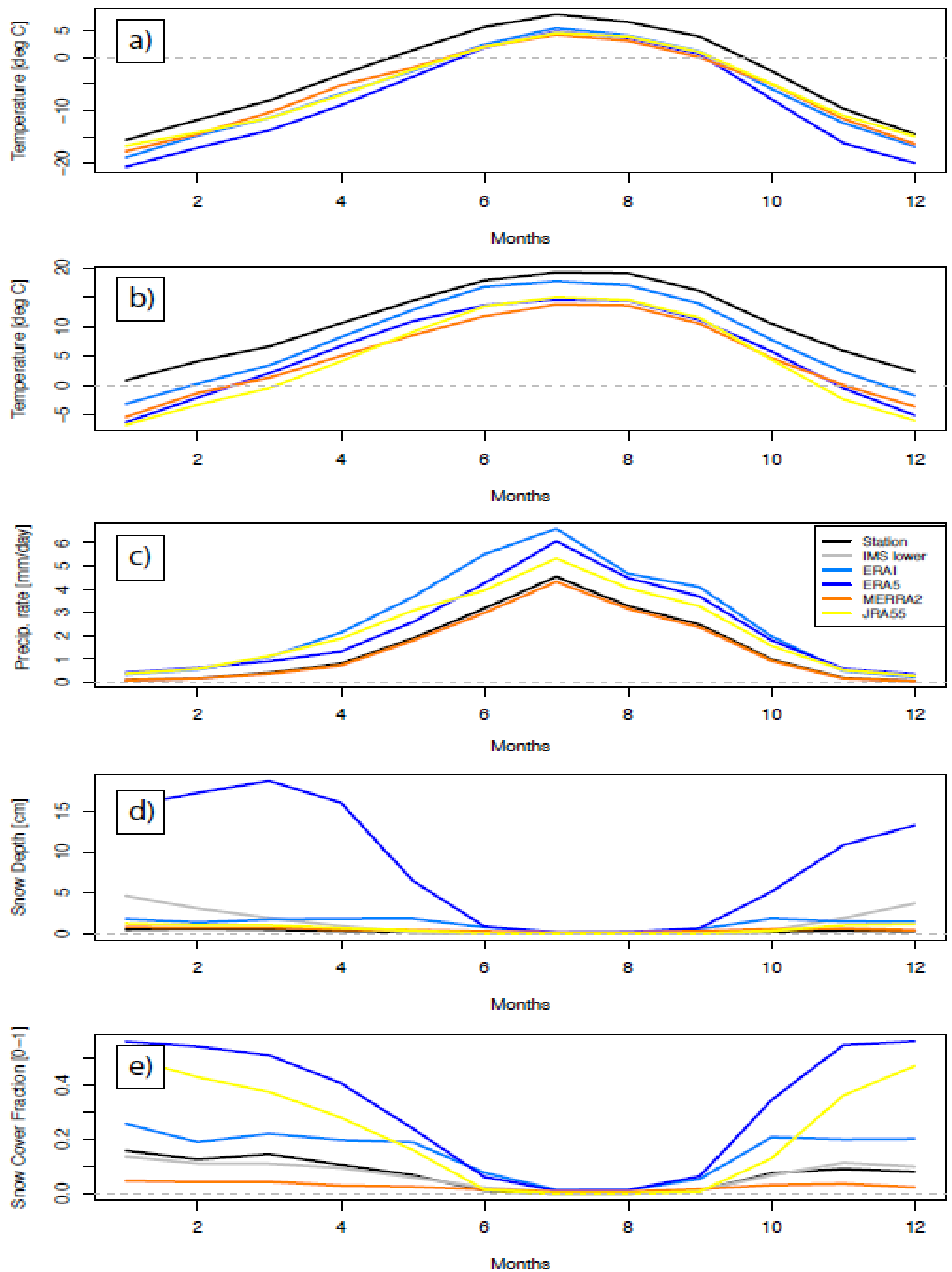
Tmin

Tmax

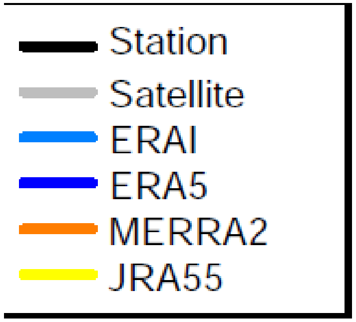
precip

SD

SCF



- Analyses have cold bias, consistent with snow excess (more snow on the ground)
- Large precipitation bias (except MERRA2 -> use observed precip dataset)
- ERA5 (high resolution) better precip than ERA-I, but worst snow



Numerical weather prediction experiments at ECMWF to address the impact of satellite snow cover assimilation at high altitudes (Lead author : P. de Rosnay)

- ❑ Medium-range forecast (10 days)
- ❑ Period: September 2011 – December 2012, twice daily
- ❑ Set of 976 forecasts
- ❑ High Resolution: Tco399 (~25 km)
- ❑ Atmospheric model IFS cycle 43r3 (currently in operation)

Issue : role of assimilation of IMS snow cover in mountainous region (>1500m)

- **CTRL** : No IMS satellite snow cover DA

[corresponds to ERA5 or Operational analyses]

- **TEST** : IMS satellite snow cover DA over HTP (2D-OI)

[our new analysis]

→ Results on Wednesday morning: Impact of snow cover data assimilation over the Tibetan Plateau on Medium Range NWP

Conclusions

- Re-analyses over-estimate SD and SCF over the TP, but assimilation of snow observations (either in-situ or satellite) improves the quality

- What is the cause of the discrepancy in the ECMWF family of re-analyses: assimilation of IMS (satellite) snow cover was discontinued at high altitudes, above 1500m.
  → **ERA5** does not assimilate IMS snow cover over the TP (neither does the operational analysis), while the older **ERA-I** did, leading to high bias

- **JRA55** has best performance for SD: use of some station data from CMA, and also satellite microwave snow cover product

- Pending a solution for the common model precipitation bias, future snow reanalyses that optimally combine the use of satellite snow cover and in-situ snow-depth observations in the assimilation and analysis cycles have the potential to improve medium-range to sub-seasonal forecasts (e.g., for water resources applications).

Sensitivity studies with the land model of ERA5 (ERA5-land):

- Reducing snowfall by 50% leads to reduction in high snow bias:

→ excessive precipitation is key issue

- Introducing parametrisation for blown snow sublimation <u>does not</u> alleviate the high snow bias

Publications

- Orsolini Y., M. Wegmann, E. Dutra, G. Balsamo, P. de Rosnay, R. Senan, B. Liu, C. Zhu, K. Yang, W. Wang: Evaluation of snow depth and snow-cover over the Tibetan Plateau in global reanalyses using in-situ observations and satellite remote sensing products, submitted to The Cryosphere Discussions, in revision, June 2019 (contact: yvan.orsolini@nilu.no)

- de Rosnay P., Balsamo G., Orsolini Y., Dutra E., Liu B., Senan R., Wang W., Wegmann M., Yang K., ZhuC.: Impact of snow cover data assimilation over the Tibetan Plateau on medium range Numerical weather prediction, in prep 2019