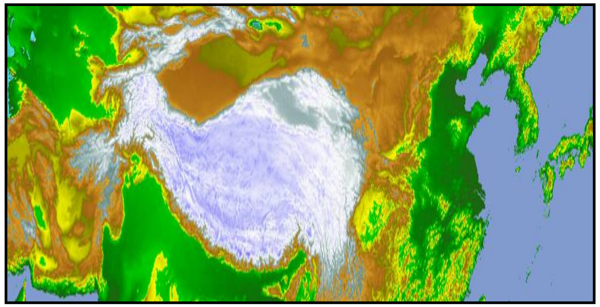


Impact of the springtime Himalayan-Tibetan Plateau snow on the onset on the Indian summer monsoon

Yvan J. Orsolini[1,2]

Retish Senan[4,] Antje Weisheimer[4], Gianpaolo Balsamo[4], Emanuel Dutra[4], Frederic Vitart[4], Francisco Doblas-Reyes[5]

[1]Norwegian Institute for Air Research - NILU, Kjeller, Norway

[2]University of Bergen, Norway

[4]ECMWF, Reading, UK

[5]ICREA, Barcelona, Spain

NILU

Motivation

- The influence of the springtime Eurasian/Himalayan snow cover for modulating the Indian summer monsoon (ISM) is also known as **Blanford's Hypothesis** (Blanford ,1884):

  - Inverse relationship between spring Himalayan snowfall and subsequent summer rainfall over Indian sub-continent

[high snowfall → weak, delayed monsoon]

- **Blanford's Hypothesis** remains controversial, despite having been the subject of many observational and model studies.
- **Issues** : in-situ vs satellite data, snow cover or depth, regional differences, short observational record
- **Physical reasoning:** the snowpack over the Himalayan and Tibetan Plateau (HTP) region (often referred to as the 3rd pole) influences the seasonal land warming:

Heavy snowpack (through radiative, hydrological and thermodynamical effects)

- reduces sensible heating, and the deep heating of the troposphere
- Slows the reversal of the meridional temperature gradient that marks the monsoon onset

Defficiencies of coupled seasonal forecast models regarding onset, total monsoon precipitation and its inter-annual variability

- **A skilful prediction depends on adequate initialisation and boundary conditions, as well as a faithful representation of the ocean-atmosphere-land coupling, namely air-sea interaction and the land-atmosphere feedbacks.**
- **inaccuracies in initialisation and misrepresentation of coupling processes.**
- **Traditionally more emphasis on air-sea interaction (ENSO, Indian Dipole, …), more recent renewed interest in land**
- **The effect of increasing model resolution has produced mitigated results.**
- **Model biases (circulation, SST, …) remain that could deteriorate skill.**

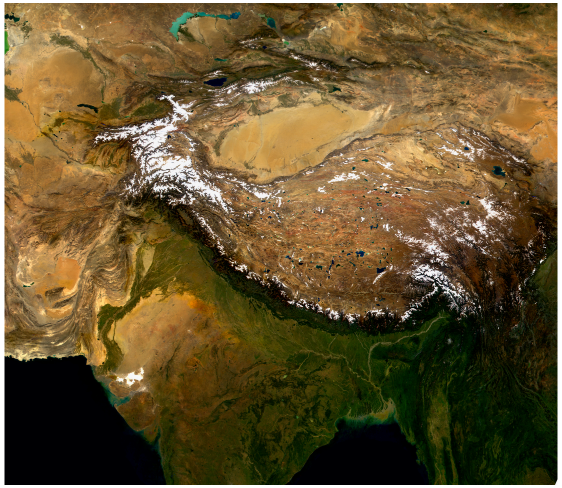
Also, onset is sometimes influenced by the initial northward migration of ISOs; recent work suggests that the atmospheric initialisation contributes to the skill, notably by improving the ISO forecast in the early monsoon period (Alessandri et al., 2015).

Our focus: revisit the role of snowpack over the Himalaya-Tibet Plateau on ISM onset

Attribute the impact of snow initialisation over the Himalaya-Tibet Plateau region (HTP) on the ISM onset, in actual predictability experiments

- Revisit the "Blanford hypothesis" with a state-of-the-art ensemble prediction system
- Coupled ECMWF seasonal forecasting system in operational mode, plus dedicated experiments
- Verification : ECMWF Atmospheric or Land Re-analyses

HTP



Modeling strategy

- Modeling strategy similar to the one initially used for looking at soil moisture impact in the warm season (Koster et al. 2004; 2010) in the GLACE international modeling project
- Twin forecast ensembles, only differing in snow initialisation

  → attribute difference to snow initialisation

- Same methodology for snow impact at high latitudes in cold season:

Orsolini, Y.J., Senan, R., Balsamo, G., Doblas-Reyes, F.J., Vitart, F, Weisheimer, A., Carrasco, A., and Benestad, R.E. Impact of snow initialization on sub-seasonal forecasts, Climate Dynamics, 41:1969-1982, 2013.

Operational forecasts

- 15-member ensemble
- atmospheric / oceanic / land

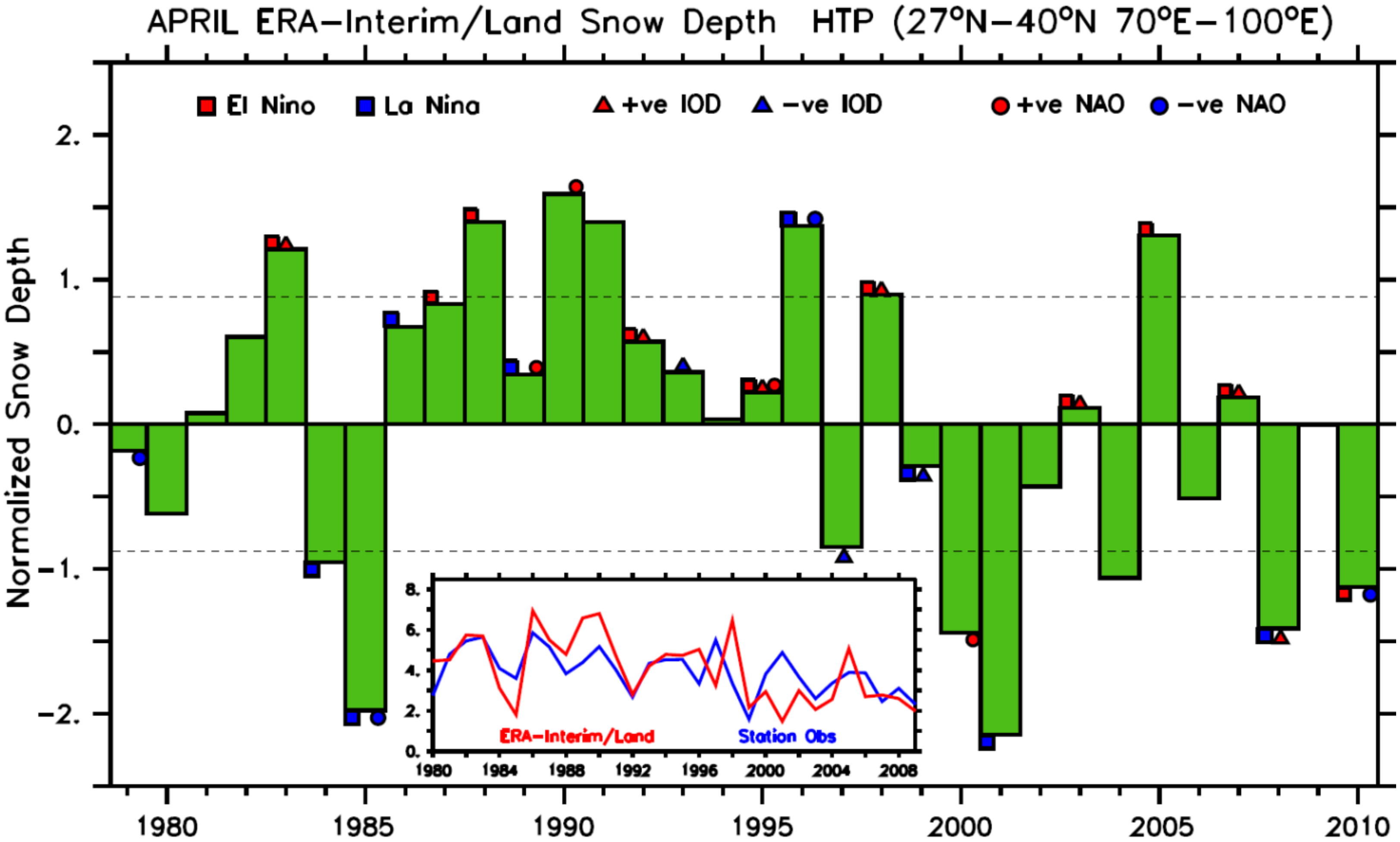
  initialisation
- forecast length : 4-month
- Start dates: APR 1
- 1979-2010

•realistic snow initialisation

using ERAINT-land

⇨ Ensemble-mean composite difference :
(High minus Low) based on a “snow index”
“Snow index” : APRIL snow depth averaged over HTP region

Snow depth over Himalaya/Tibet Plateau : ERAINT land

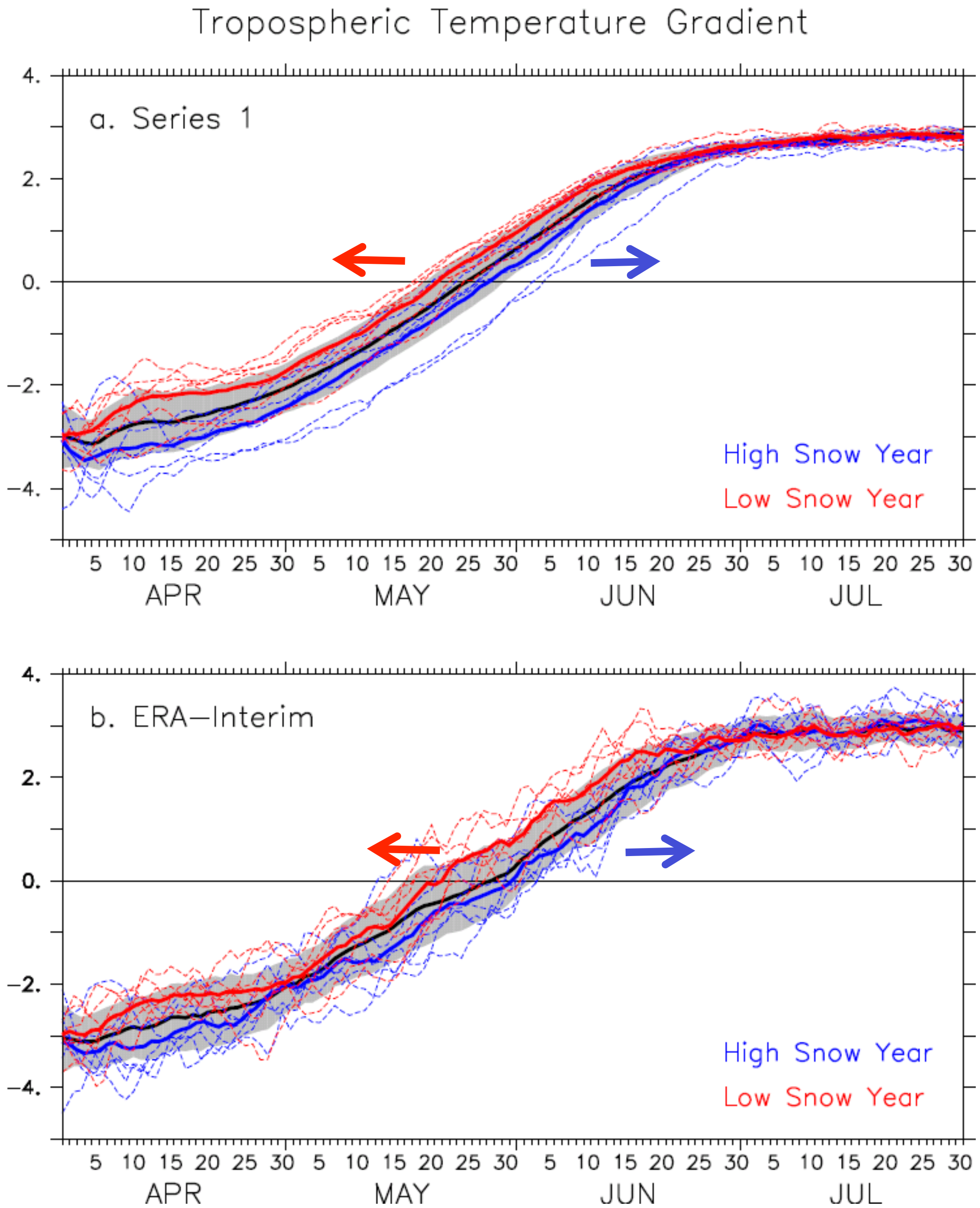


HIGH:
7 years

LOW:
7 years

- Inset : comparison with 47 station data over Tibet (courtesy of D. Basang, GFI-Bergen): corr =0.57 : analyses captures snow inter-annual variability

ISM ONSET as reversal of tropospheric temp. gradient (TTG)

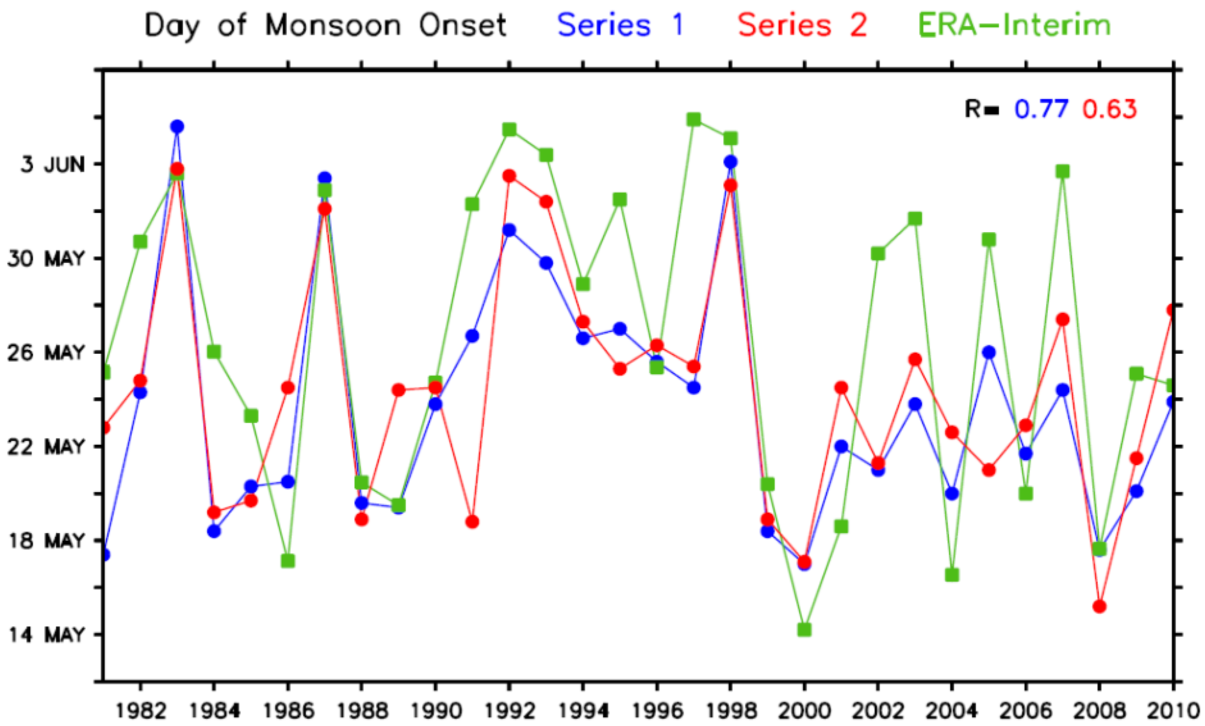


- **Reversal occurs earlier/later (← or →) or later in May in low/high April snow years over HTP region**
- **Average delay in onset is about 1 week**
- **Note: onset corresponds at a lead time : 2 months**
- **Note: S1 is the (smooth) ensemble mean**

Based on (Xavier et. al, 2007)

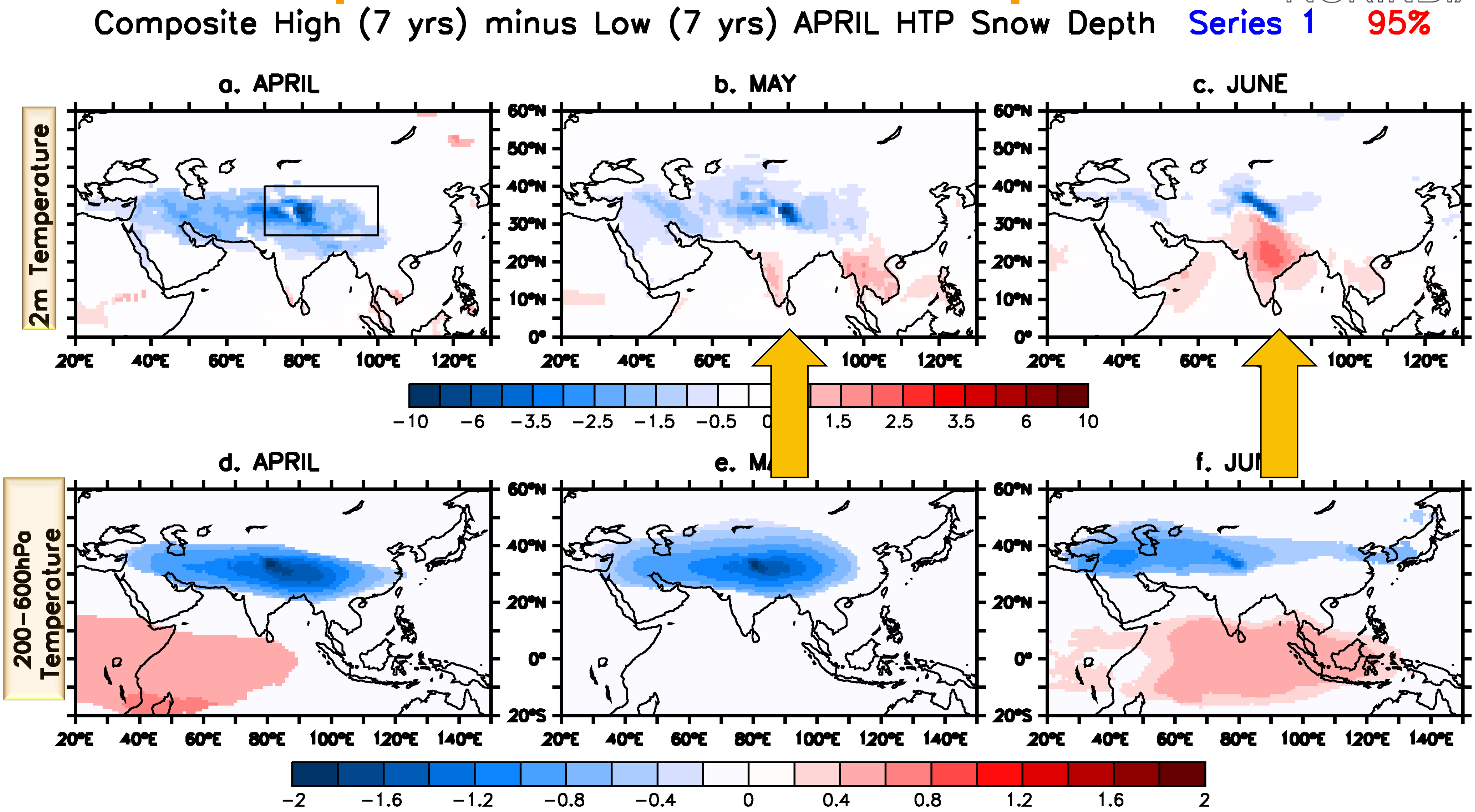
- **TTG : difference of the vertically integrated (200-600hPa) temperature, between a northern region (5°N-35°N) and southern region (15°S-5°N) over 40°E -100°E**
- **Onset of the monsoon: TTG zero-crossing (in late May)**

Date of ISM Onset



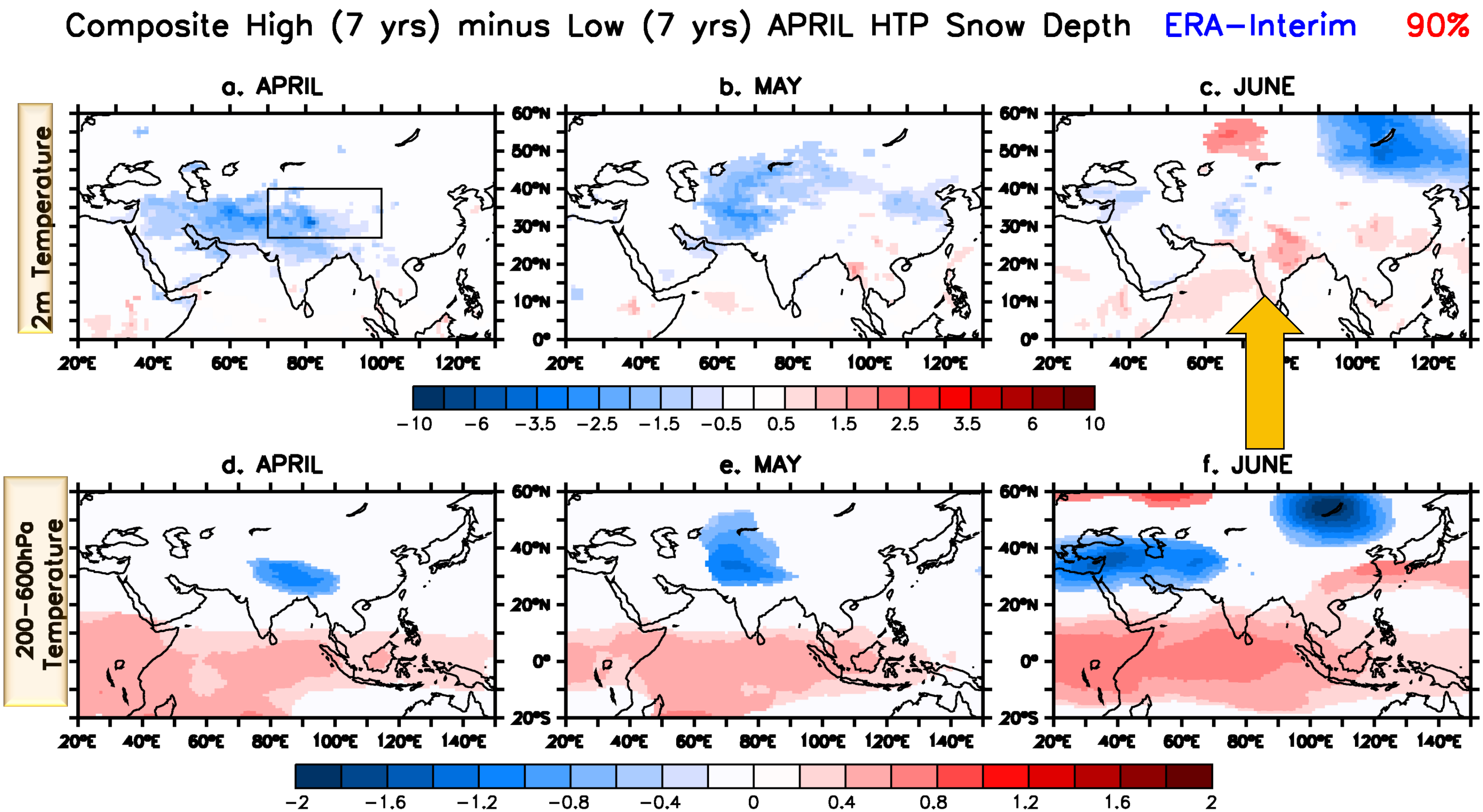
- Model has early onset bias compared to ERAINT (3 days)
- Most coupled models late onset bias, probably related to SST positive biases over equatorial Pacific according to Prodhomme et al. (Clim Dyn, 2014)
- Good correlation of inter-annual variability (0.77)

Snow composite differences: temperature



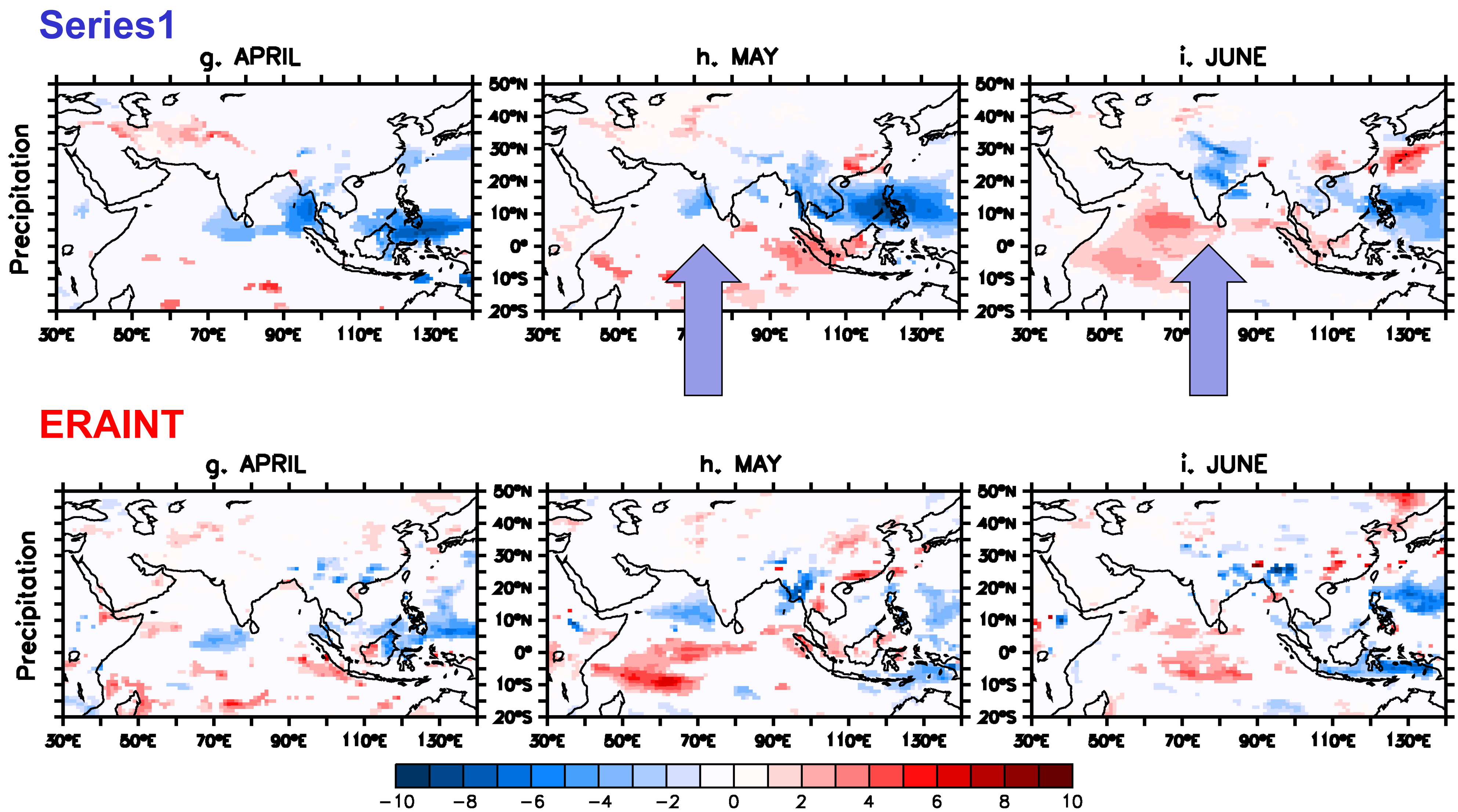
- High APRIL HTP SNOW: warm anomaly in MAY-JUNE over India
- Consistent with delayed monsoon

Snow composite differences: temperature



- High APRIL HTP SNOW: warm anomaly in JUNE over India
- Consistent with delayed monsoon

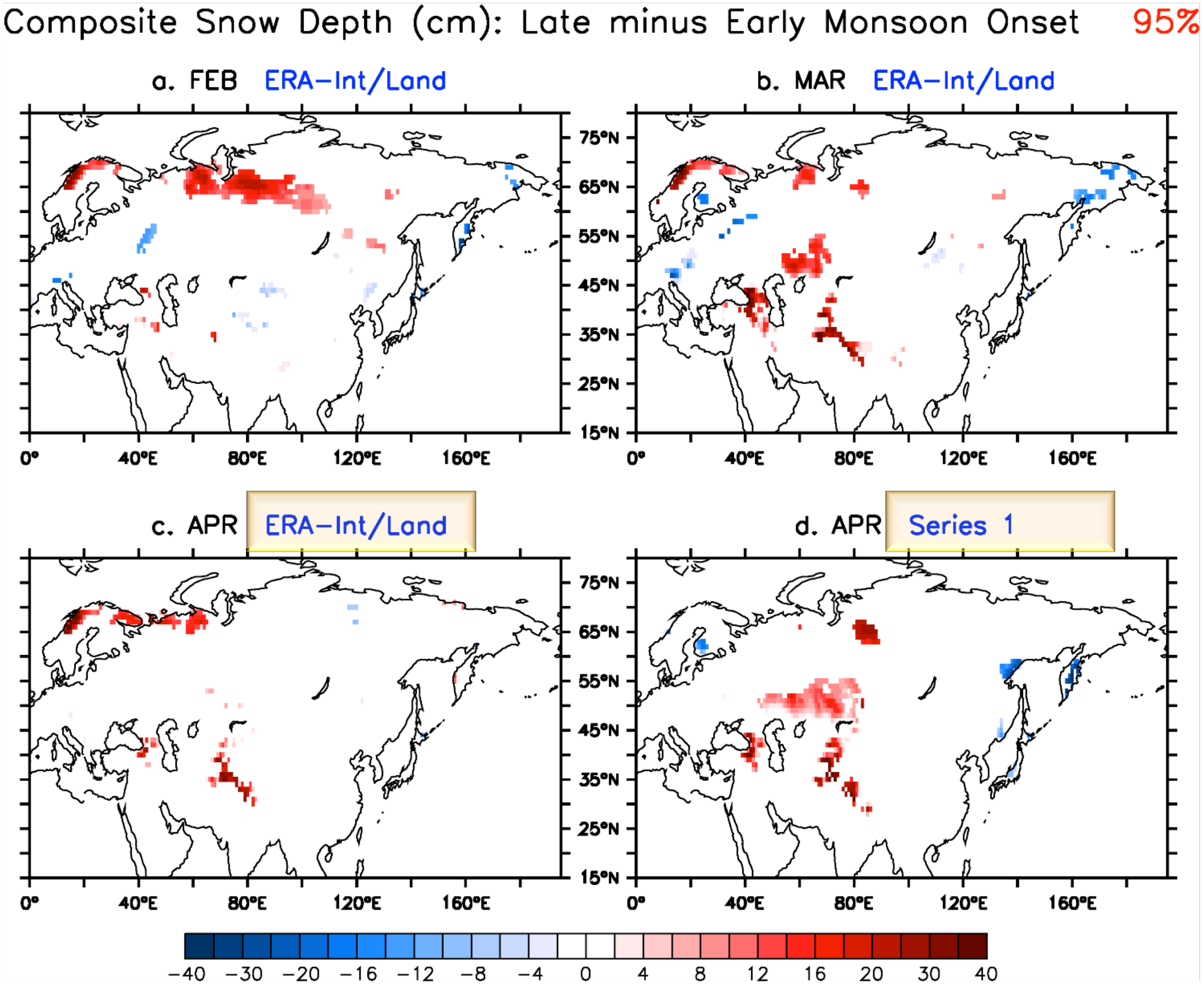
Snow composite differences: precipitation



- High APRIL HTP SNOW (model): precipitation deficit in MAY over Arabian Sea/Bay of Bengal and in JUNE over Indian subcontinent
- Consistent with delayed, weak monsoon

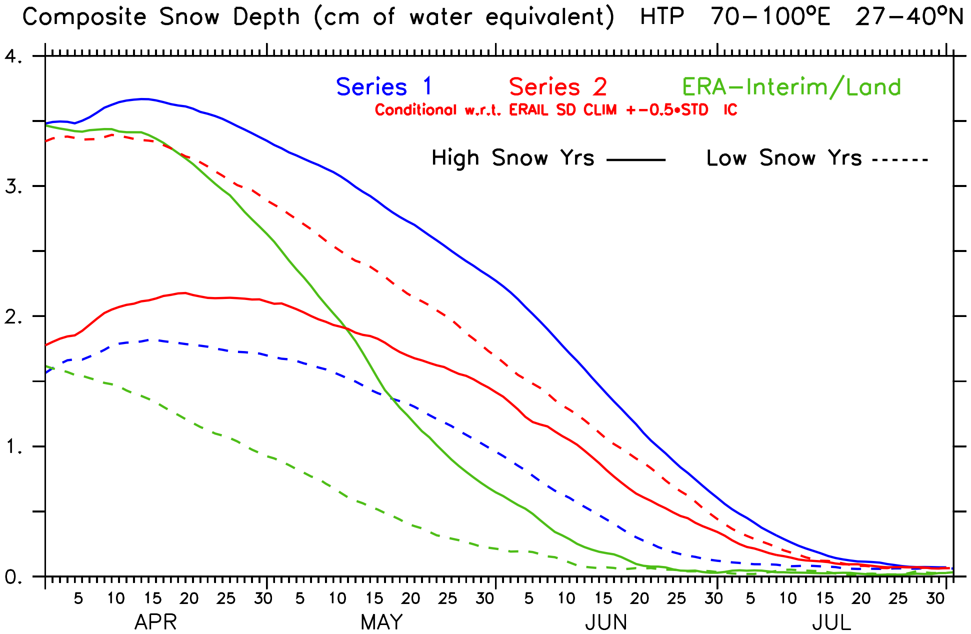
Monsoon Onset Composite
(Reciprocal relation)

APRIL →



- Late onset consistent with high HTP SNOW anomaly in APR (precursory signal)

Series 2 dedicated forecasts: role of HTP snow initialisation



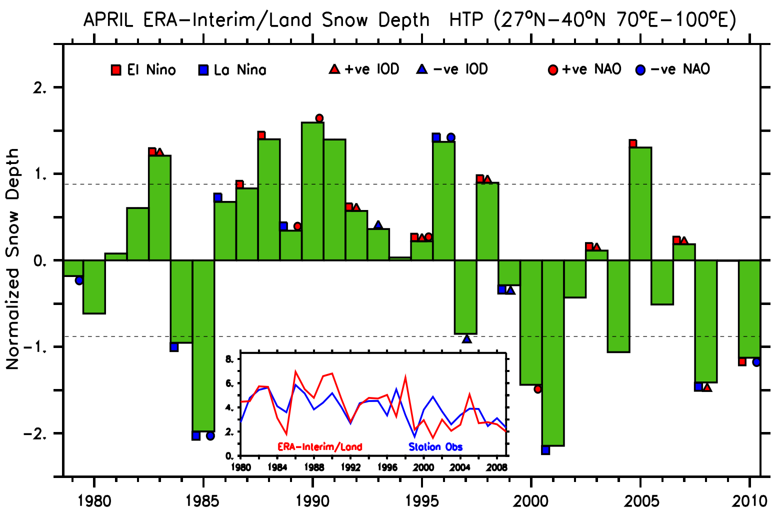
ONSET DATE	ERA-Interim	Series 1	Series 2 Conditional CLIM ± 0.5*STD
Mean Onset Day	May 29	May 26	May 25
Mean Onset Day: High Snow Years	May 31	May 28	May 26
Mean Onset Day: Low Snow Years	May 22	May 21	May 22
Onset Diff: High Snow minus Low Snow Years	9	7	4

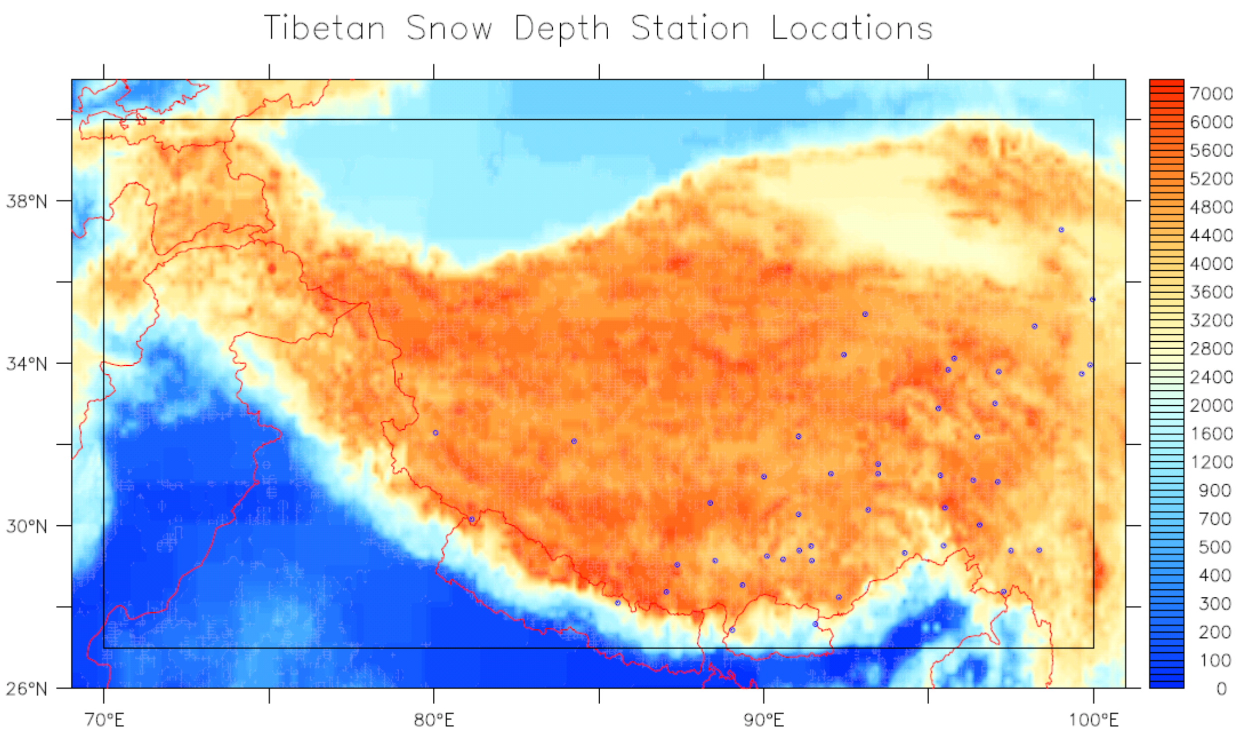
- Series 2 forecasts: randomized snow over HTP
- 50% of the delay can be attributed to snow initialisation over HTP
- the other half : atmospheric preconditioning (atmospheric initial conditions creating the snow anomaly), SSTs, Eurasian snow ….

Q1) How realistic is the snow depth reanalysis (based on ERAINT-land) over HTP ?

- corr= 0.57 with set of 47 stations, mostly at low elevation, with inhomogeneous distribution while there may be complex regional climate regimes
- How are the regional seasonal climatic regimes represented?
- Station data is April snow max : is there a high snow model bias over HTP, common to many re-analyses with impact on forecasts

→over-estimating effect of snow on monsoon

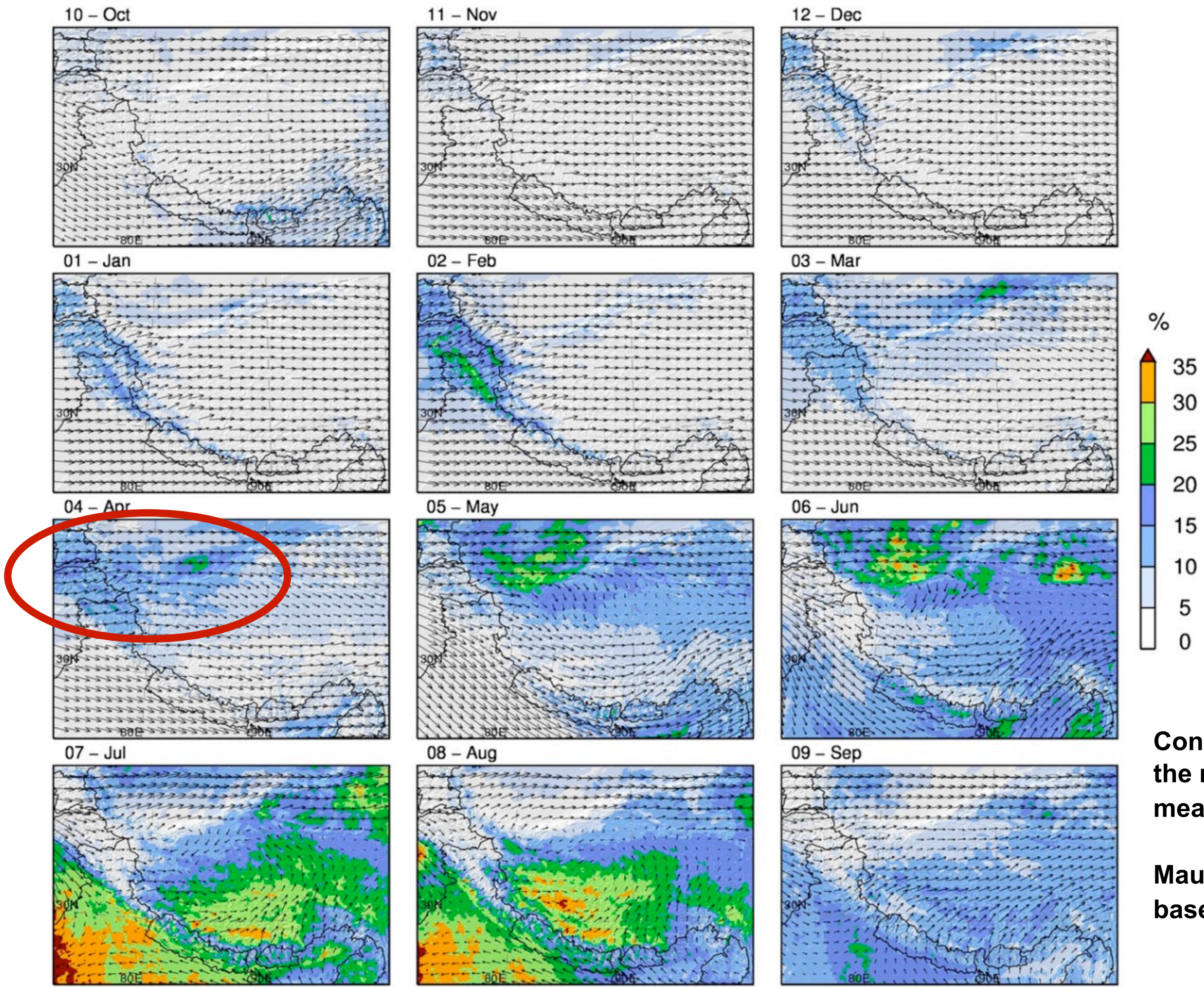




Q1) How realistic is the seasonality of precipitation in reanalysis over HTP

- mostly summer monsoonal precipitation in central TP, dry in winter
- most studies on precipitation focused on winter and summer, but spring has been little assessed

APRIL →

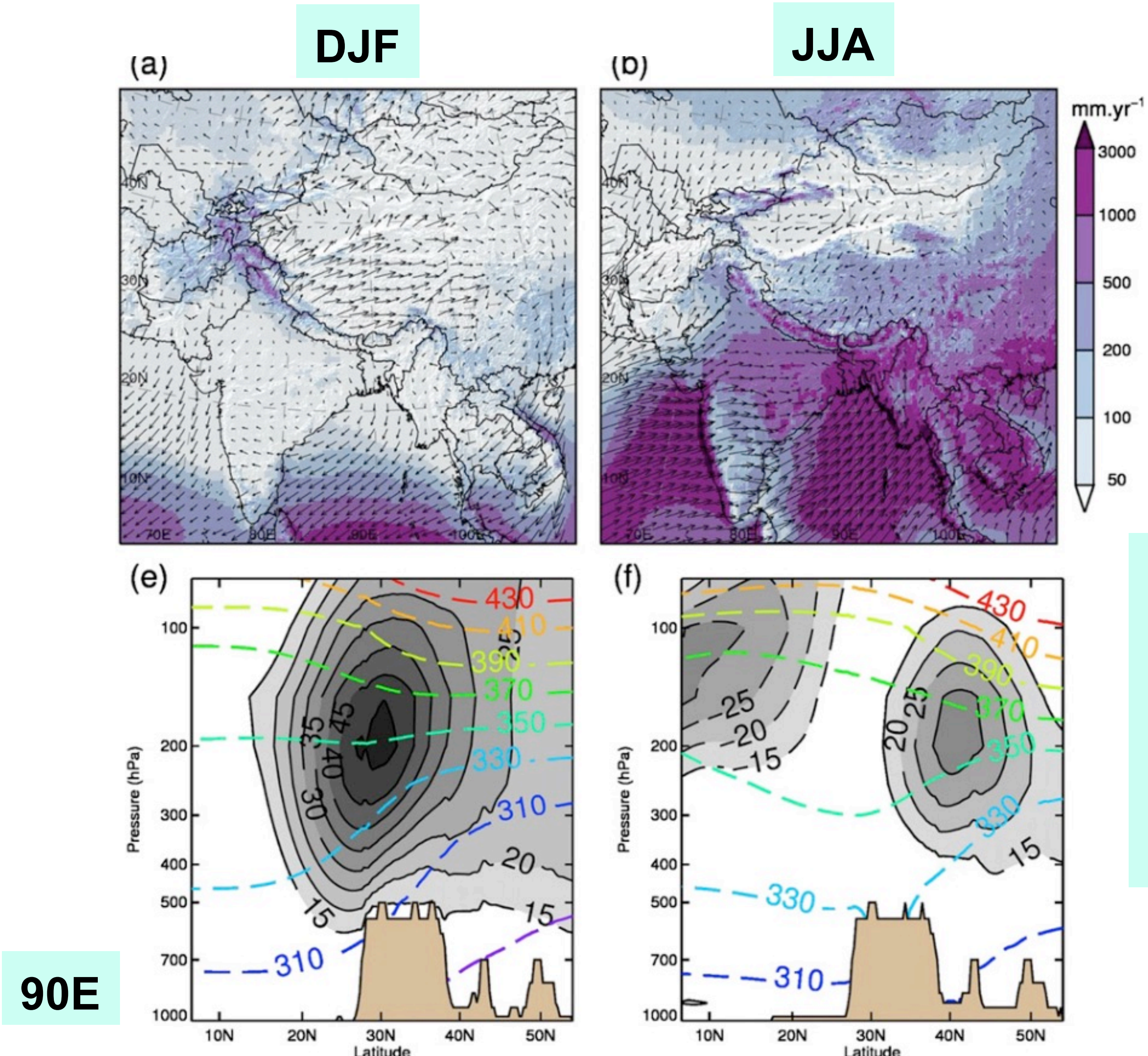


Contribution (%) of each month to the mean annual precipitation and mean monthly 500-hPa wind

Maussion et al., 2014
based on regional HR reanalysis

Q1) How realistic is the seasonality of precipitation in reanalysis over HTP

- mostly summer monsoonal precipitation in central TP, dry in winter
- most studies on winter and summer, but spring has been little assessed



Decadal mean seasonal precipitation (2001-2011)

and jet stream

Maussion et al., 2014

weaker summer jet

(also wavetrain: Silk Road teleconnection from Europe to Far East)

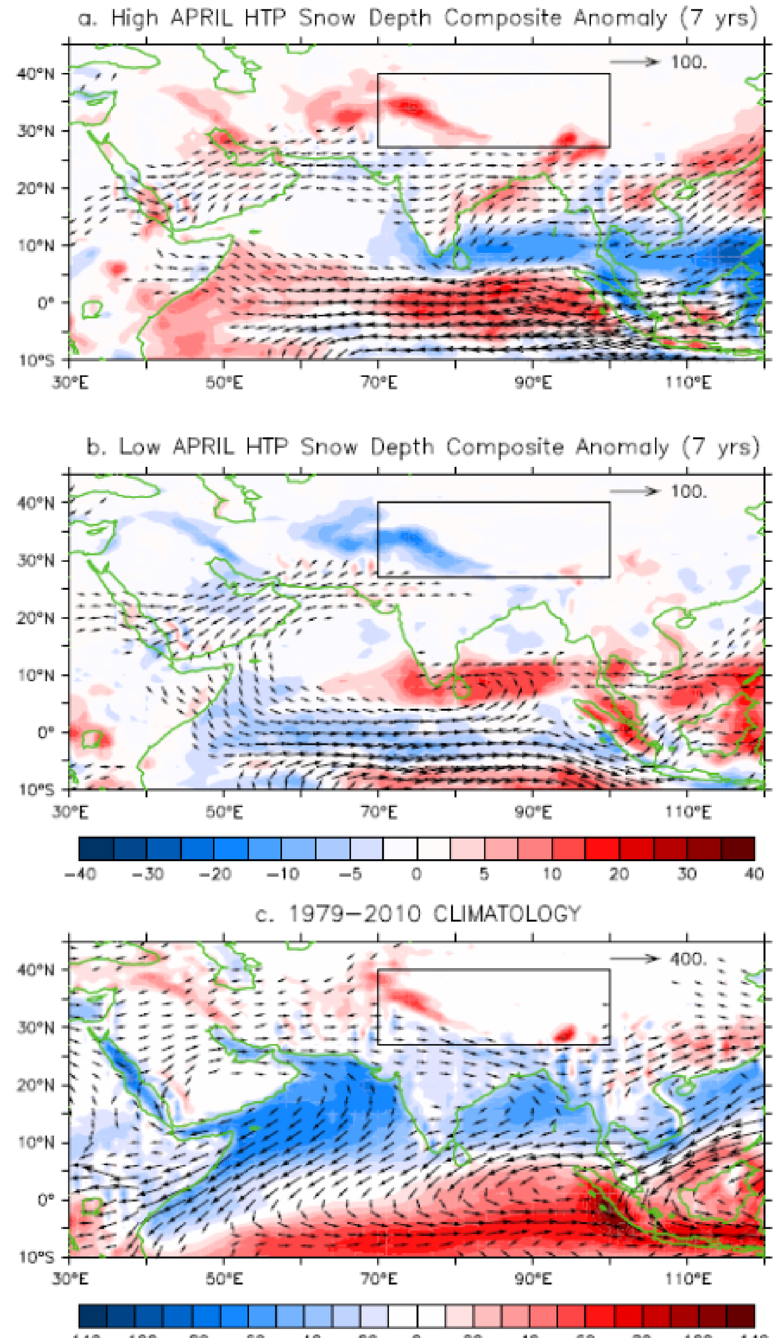
Q2) Origin of precipitation over HTP ?

DJF preceding
HIGH APRIL snow

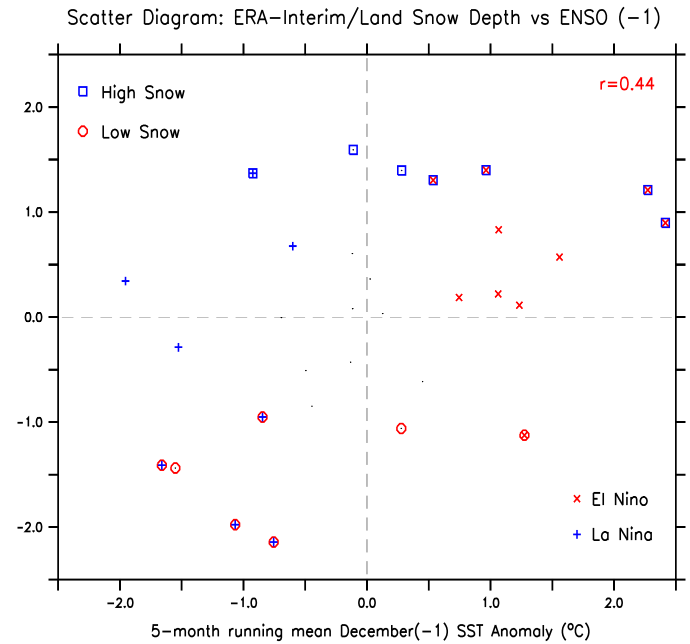
Region of enhanced convergence

DJF preceding
LOW APRIL snow

DJF clim



ENSO



No particular patterns examined (ENSO, NAO, IOD) in previous winter months uniquely determine APR snow

Q2) Origin of precipitation over HTP ? (continued)

winter

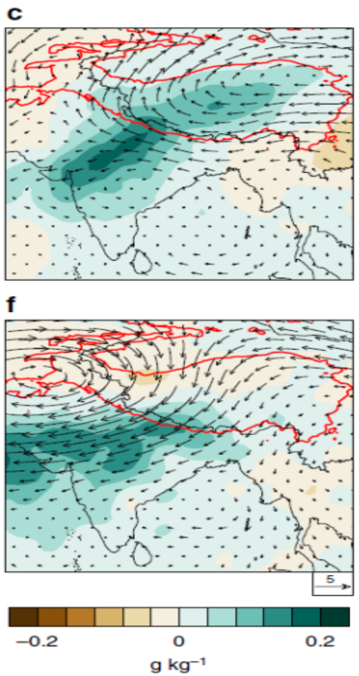
- role of "westerly disturbances" (Tiwari et al., 2017)
  50% total annual precip over Western Himalaya by a few (<10) of these eastward-travelling baroclinic transient eddies

winter

- also a modulating role of low-latitudes (ENSO, MJO) ? (Cannon et al., 2017)

Summer

- "Up and over" transport of moisture (Dong et al., 2016): few intrusive convective systems carry moisture to the southwestern TP



Intrusive

vs

Non-Intrusive

Moisture anomalies at 300 hpa + ERAINT winds

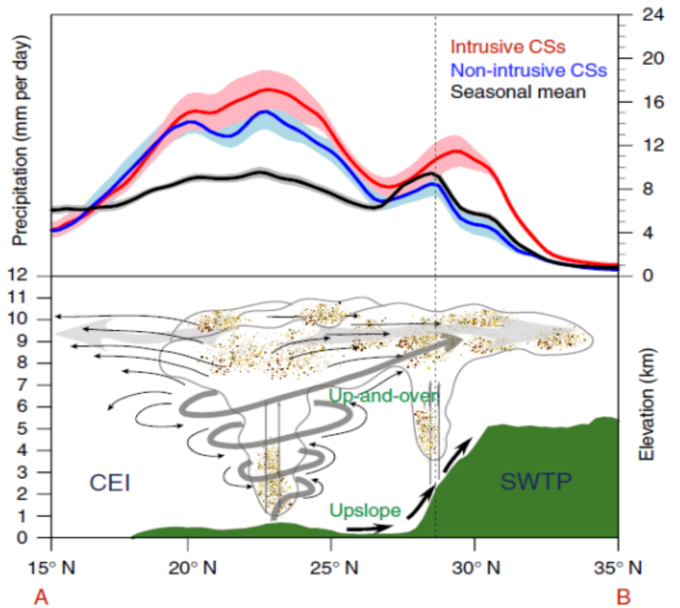


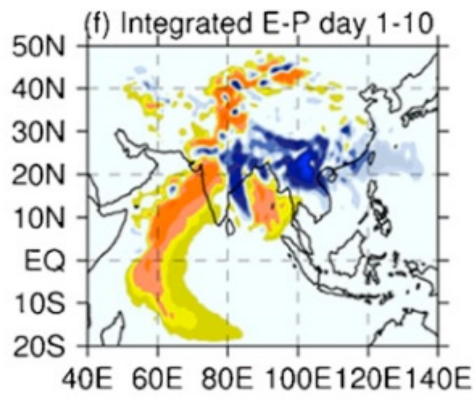
Figure 7 | Precipitation profiles and a schematic of the up-and-over transport. Mean precipitation averaged over the black box marked in Fig. 5a

from Wenhao Dong, Nat. Comm., 2016

Q2) Origin of precipitation over HTP ?
(continued)

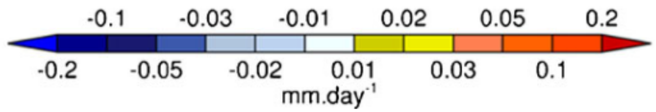
Summer

2005–2009



Long-range source of moisture

(backwards Lagrangian traj., E-P)



From Bin Chen et al.,, 2012

Q3) Any benefits of land data assimilation ?

❑ snow assimilation (Lin et al., 2016) into CLM of
→ MODIS snow cover
→ GRACE water storage

Seasonal forecasts with CAM5 model
→Snow assimilation improves T prediction over HTP (5-20%) with effects already at short lead times

Q4) Snow impact on early monsoon rainfall, in addition to onset

- Halder and Dirkmeyer (2017) observation-based study: one step further than Senan (2016)

→ spring snow affects rainfall during initial monsoon (30 days and 60 days)

- delayed hydrological effect (snow→soil moisture) is key
- Dynamical feedback on mid-latitude wave train/monsoon interaction: →anchoring intrusions of mid-latitude troughs, reducing convection.

Spring

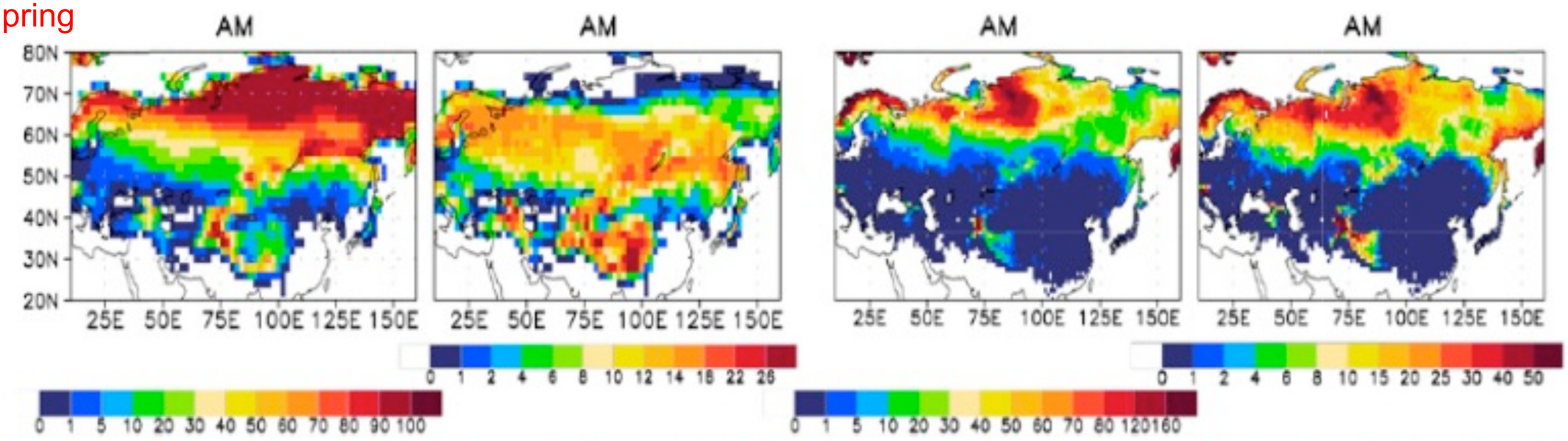


FIG. 1. (left) Mean and (center left) interannual std dev of NOAA/NESDIS monthly SCF (%) averaged during (top) DJ, (middle) FM, and (bottom) AM from 1967 until 2003. (center right),(right) As in (left) and (center left), but for monthly GLDAS-2.0 SWE (kg m^{-2}).

Snow cover fraction : mean and std dev

Snow water equivalent: mean and std dev

Q5) stationarity of the relation HTP snow / monsoon onset

spring

- climate re-analyses going back to late 19th or early 20th century (20CR, ERAC, CERA)

Reasonable representation of Eurasian snow variability, even in early pre-50s era (Wegmann et al, 2017)

but divergent states between 20CR and ERAC

Is this true also over HTP ?

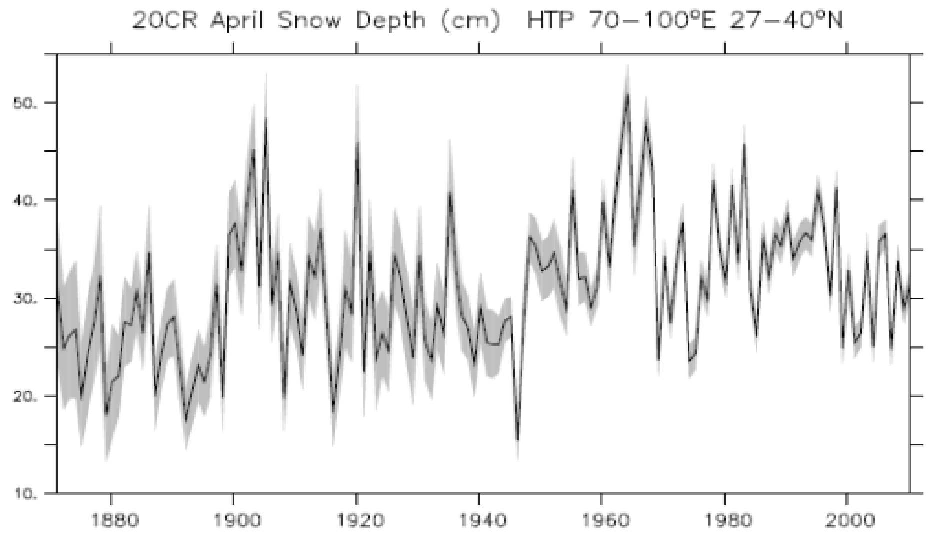


FIG. 1. Time series of monthly mean snow depth (cm) in April over the Himalayan-Tibetan plateau (27°N-40°N, 70°E-100°E) region. The gray envelope shows the spread of the ensemble.

- Reassess the relation over long term ? Link to decadal changes over HTP

Q6) Other points

- International efforts for regional climate analyses (regional models, WFR?)
- High-resolution global re-analyses ?
- SNOWGLACE experiments at ECMWF: the spring runs (initialized on MAR 1) have not much diagnosed

Conclusion

- ❑ Revisit the influence of springtime Eurasian/Himalayan snow cover on Indian summer monsoon (ISM) onset using modern, dynamical prediction system

- ❑ ECWMF seasonal (coupled) ensemble prediction system (operational + dedicated, attribution experiments)

- ❑ High snow over HTP in April leads to a delay of monsoon onset (9 days)

- ➢ Half of the delay is attributable to the HTP snow initialisation, the rest comes from atmospheric preconditioning, SST or snow initialisation over Eurasia

(more dedicated experiments needed to ascertain the role of these factors separately, and of processes (e.g. hydrological vs thermodynamical)

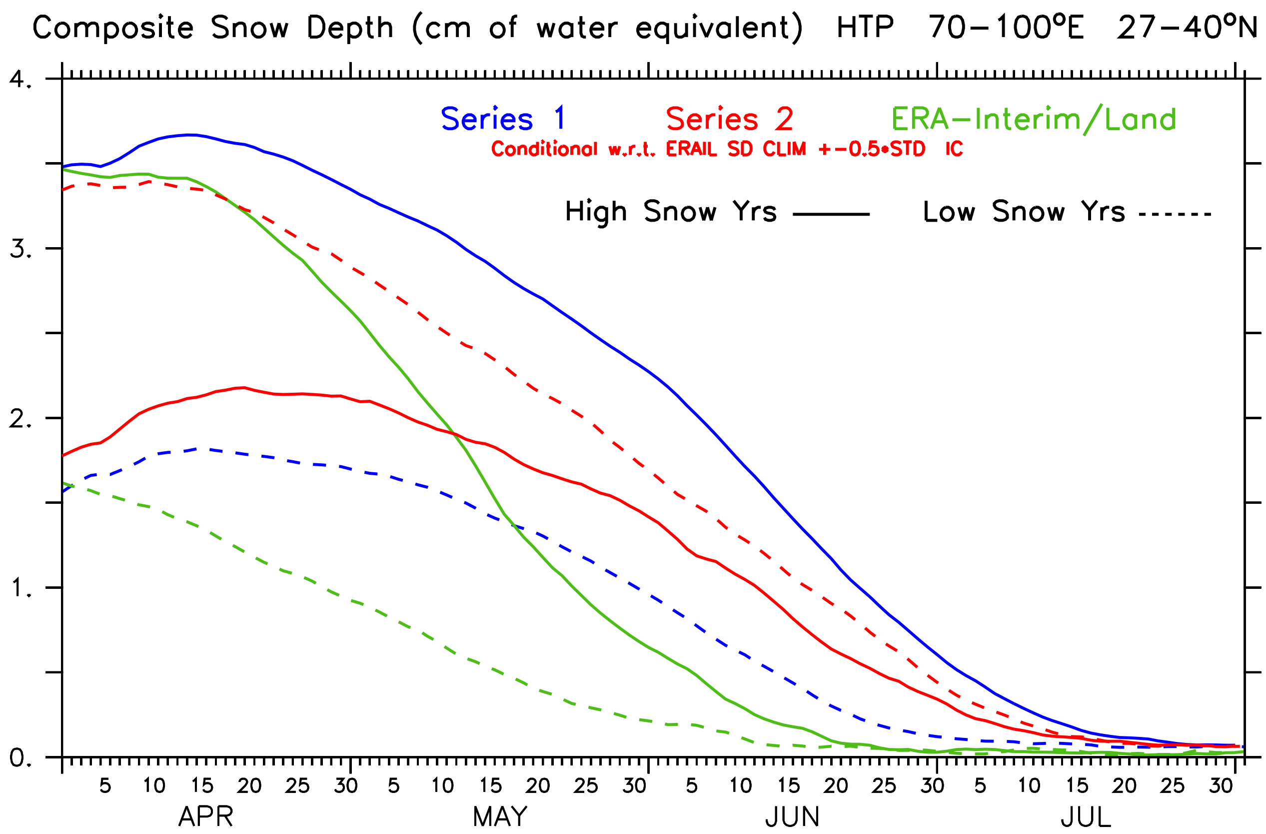
Orsolini, Y.J., Senan, R., Balsamo, G., Doblas-Reyes, F.J., Vitart, F, Weisheimer, A., Carrasco, A., and Benestad, R.E. Impact of snow initialization on sub-seasonal forecasts, Climate Dynamics, 41:1969-1982, 2013.

Senan, R., Orsolini, Y.J., Weisheimer A., Vitart, F., Balsamo, G., Stockdale, T., Dutra, E., Doblas-Reyes, F., D. Basang, Impact of springtime Himalayan-Tibetan Plateau snowpack on the onset of the Indian summer monsoon in coupled seasonal forecasts, Clim. Dyn., Vol. 47, Issue 9, pp 2709–2725, doi:10.1007/s00382-016-2993-y. (2016)

Orsolini, Y.J., Senan, R., Vitart, F., Weisheimer, A., Balsamo, G., Doblas-Reyes F., Influence of the Eurasian snow on the negative North Atlantic Oscillation in subseasonal forecasts of the cold winter 2009/10, Clim. Dyn., vol47, 3, pp 1325–1334, DOI: 10.1007/s00382-015-2903-8 (2016)

Reserve slides

Snow depth evolution over HTP : forecast and ERAINT-land



- Model: high snow bias over HTP region

→Snowpack doesn't decay as fast as ERAINT-land

(also grows, likely excessive precipitation)

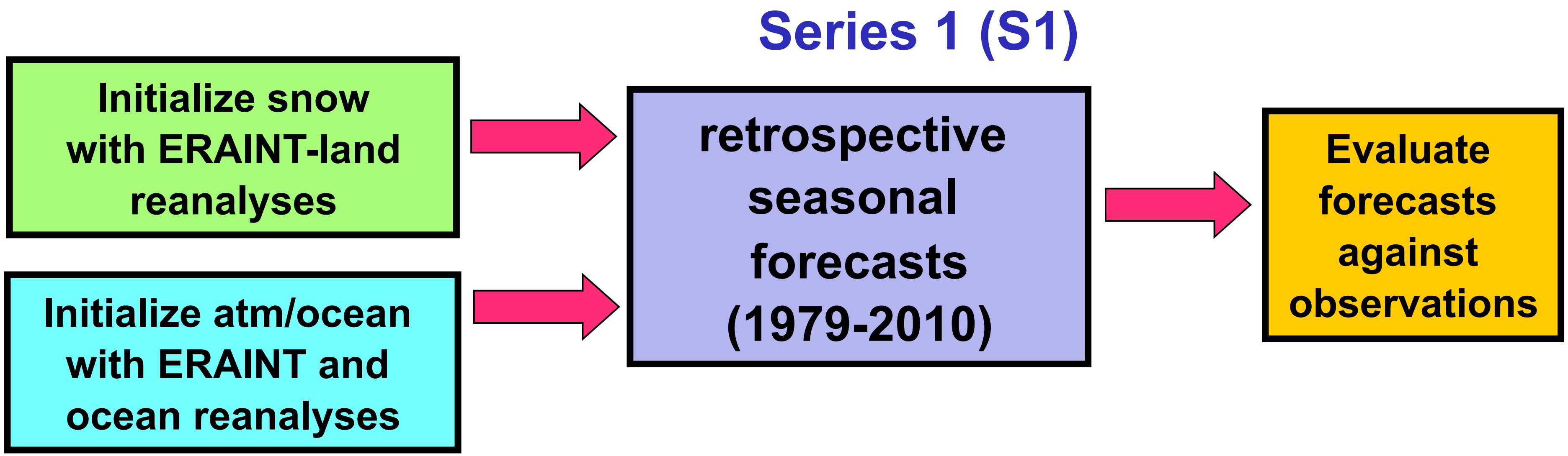
Defficiencies of coupled seasonal forecast models regarding onset, total monsoon precipitation and its inter-annual variability

→In NCEP/CFS, basin-wide low-level circulation biases, with weak anticyclones over the Indian and Central Pacific Oceans, and related cold SST biases over the Arabian Sea, are factors that could contribute to the dry bias over Central India and to the weakness of the meridional tropospheric temperature gradient (TTG).

→In UKMO model, weak air-sea interaction over the Indian Ocean and negative bias in low-frequency surface wind variance in the Indian Ocean cause unrealistic propagating ISO in the UKMO operational model

A first series of seasonal forecasts with realistic snow initialisation

(current operational model – known as System4)

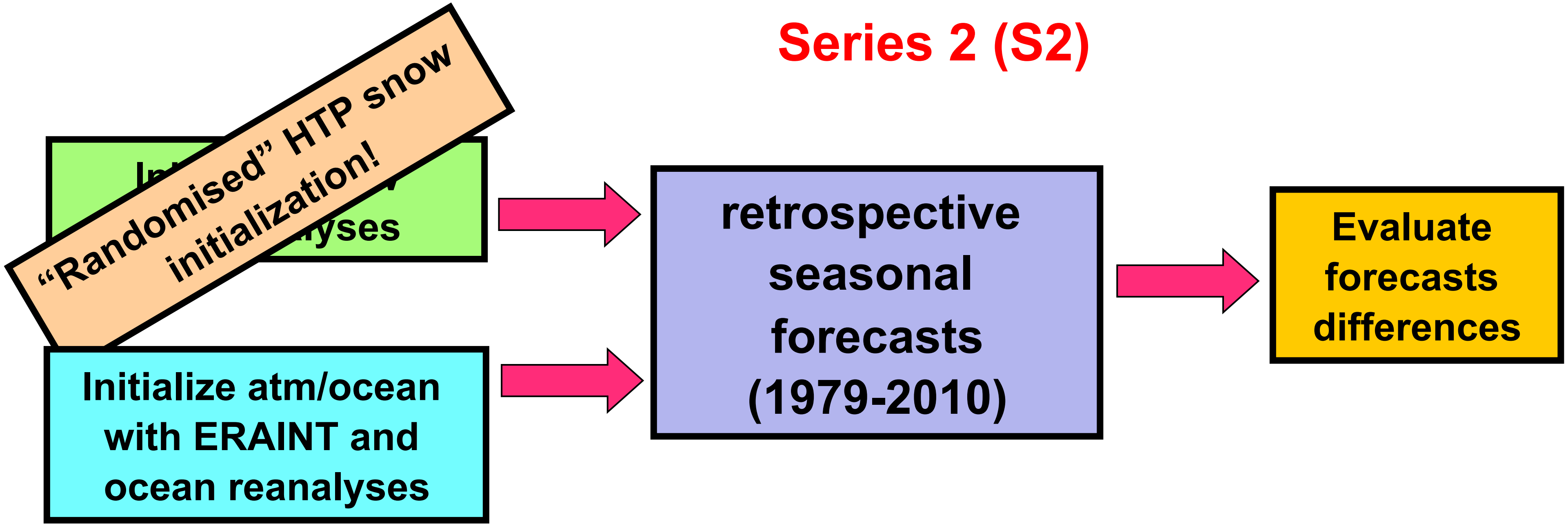


- High horizontal resolution (T255;l62) coupled ocean-atmosphere model
- State-of-the-art ensemble prediction system
- Improved land surface module, hydrology and snow scheme

Following GLACE soil moisture approach (Koster et al. 2004; 2010)

A second ensemble of seasonal forecasts with ”randomised” snow initialisation over HTP

(Dedicated forecasts for attribution)



Series 1: Operational forecasts

- 15-member ensemble
- atmospheric / oceanic / land initialisation
- forecast length : 4-month
- Start dates: APR 1
- 1979-2010

•realistic snow initialisation

using ERAINT-land

Series 2: dedicated forecasts

identical , but

•“randomised” snow over HTP: APR 1 from other years in ERAINT-land

Ensemble-mean composite difference in S1:
(High minus Low) based on a “snow index”
“Snow index” : APRIL snow depth averaged over HTP region