1. Contributions to Developing GEWEX Science and the GEWEX Imperatives:

a. <u>Datasets</u>
- Monsoons Panel (MP) & its regional WGs use only the publicly available observational and model datasets to study monsoons all over world to understand its unique features.
- Any observational datasets collected in future by MP members could contribute to GEWEX science development.

b. <u>Analysis</u>
- MP and its regional WGs are expected to develop new analysis tools and software that will be available to the community.
- The preliminary theoretical development of a South-East Asian Monsoon Progression Index was completed using CDAS and ERA5 datasets.
- Hindcasts from different models were assessed to understand the strengths and limitations in South Asian Monsoon rainfall predictions.

c. <u>Processes</u>
- MP and its regional WG members are actively involved in process understanding and model treatment (e.g., precipitation, clouds, surface fluxes, coupling surface to atmosphere, aerosols, dynamics-physics coupling).

d. <u>Modeling Activities</u>
- Assess and improve the skill of monsoon rainfall prediction in different regional monsoons and identify the bottlenecks in the dynamical models.
- Improve understanding of dynamical and physical processes associated with extreme events and identifying the lacuna in capturing these extremes in present-day models.

e. <u>Application</u>
- MP & its regional WGs intend to suggest improvements in both weather and climate models through model evaluation, especially on extreme events.

f. <u>Technology Transfer</u>
- MP & its regional WGs intend to promote Research to Operations (R2O) activities to contribute with the Regional Climate Outlook Forums (RCOFs) and operational meteorological services.

g. <u>Capacity Building</u>
- Build capacity by promoting ECS representation in the WGs and subgroups developing these activities. About seventeen (17) members of MP and its regional working groups are early career researchers.
- Several of the members of WG on Asian-Australian Monsoons (WG-AAM) are regular contributors to the Regional Climate Outlook Forums for the Asian-Australian region (SASCOF, ASEANCOF, EASCOF), allowing the group to provide guidance on model strengths and weaknesses and to reach out to stakeholders

2. **Contributions to the GEWEX Science Questions and Plans to Include These:**

a. <u>Observations and Predictions of Precipitation</u>
- Annalisa Cherchi (Member) contributed to a draft white paper on WCRP Global Precipitation Experiment as a representative of MP in GPEX tiger team. MP members also made several suggestions to the draft white paper.

b. <u>Global Water Resource Systems</u>
- MP & its regional WGs are focusing on extreme weather events leading to large scale/flash flooding.

c. <u>Changes in Extremes</u>
- MP & its regional WGs intend to suggest improvements in both weather and climate models through model evaluation of extreme events.
- There is a High Impact Weather (HIW) events sub-group under WG-AAM, which is focusing on high impact events from recent years for (i) case studies in terms of observations and forecasts (ii) linking operational forecasts to decision making (iii) how monsoon research can best support hazard mitigation. (iv) do forecasting frameworks need to adjust to account for socio-economic /climate change.

d. <u>Water and Energy Cycles</u>
- MP & its reginal WGs aim to improve weather and climate models, including their capability for studying the water and energy cycles through model evaluation studies (e.g., CMIP, DYAMOND)

3. **Contributions to WCRP, Including the Light House Activities:**
- Activities of MP & WGs aim to improve weather and climate models, enabling the modeling study of weather and climate "Extremes".
- High Impact Weather (HIW) events sub-group under WG-AAM, is focusing on high impact events from recent years during the monsoon seasons (pl. see 2c above for details), which could lead to contributions to "Understanding High-Risk Events" LHA
- There are some discussions in HIW sub-group on how AI or Machine Learning could be used to enhance the warnings, and on the potential for involving social scientists to help understand public response to warnings. This could lead to contributions to "Digital Earth" LHA under "advanced digital technology"

4. **Other Key Science Questions:**
   List 1–3 suggestions that you anticipate your community would want to tackle in the next 5–10 years within the context of a land-atmosphere project

- How realistic are the high-resolution simulations of extreme rainfall events compared to the observations? How can we improve the model predictions of monsoon rainfall and associated extreme events?
- How does land surface temperature (LST) over global high mountain regions (including the Himalayas, Rocky Mountains, Andes mountains and other high mountains) affect the global monsoon precipitation at S2S scales?

5. **Cooperation with Other WCRP Projects, Outside Bodies and Links to Applications:**
   e.g., CLIVAR, CliC, SPARC, Future Earth, etc.
   - SPARC, S2S Prediction Project
   - MP is engaged in interactions with SPARC on the role of atmospheric composition in processes relevant for the monsoons, including the Atmospheric Composition and Asian Monsoon (ACAM) activity of SPARC (https://www.sparc-climate.org/activities/asian-monsoon/).
   - IMPO (project office of MP) personnel provide wiki page support for regional activities of S2S in South Asia.

List contributions to the GEWEX Science Goals and plans to include these.
Goal # 1 (GS1): Determine the extent to which Earth's water cycle can be predicted. This Goal is framed around making quantitative progress on three related areas posed in terms of the following questions:

- Reservoirs:
  What is the rate of expansion of the fast reservoirs (atmosphere and land surfaces), what is its spatial character, what factors determine this and to what extent are these changes predictable?
  ....
- Flux exchanges:
  To what extent are the fluxes of water between Earth's main reservoirs changing and can these changes be predicted and if so on what time/space scale?
  ....
- Precipitation Extremes:
  How will local rainfall and its extremes change under climate change across the regions of the world?
  The High Impact Weather (HIW) events sub-group under WG-AAM, is focusing on high impact events from recent years for (i) case studies in terms of observations and forecasts (ii) linking operational forecasts to decision making (iii) how monsoon research can best support hazard mitigation. (iv) do forecasting frameworks need to adjust to account for socio-economic /climate change.

Goal # 2 (GS2): Quantify the inter-relationships between Earth's energy, water and carbon cycles to advance our understanding of the system and our ability to predict it across scales:

- Forcing-feedback understanding:
  How can we improve the understanding of climate forcings and feedbacks formed by energy, water and carbon exchanges?
  ....
- ABL process representation:
  To what extent are the properties of the atmospheric boundary layer (ABL) defined by sensible and latent energy and water exchanges at the Earth's surface versus within the atmosphere (i.e., horizontal advection and ABL-free atmosphere exchanges)?
  ....
- Understanding circulation controls:
  To what extent are exchanges between water, energy and carbon determined by the large-scale circulations of the atmosphere and oceans?
  ....
- Land-atmosphere interactions:
  How can we improve the understanding of the role of land surface-atmospheric interactions in the water, energy and carbon budgets across spatio-temporal scales?
  ....

Goal # 3 (GS3): Quantify anthropogenic influences on the water cycle and our ability to understand and predict changes to Earth's water cycle.

- Anthropogenic forcing of continental scale water availability:
  To what extent has the changing greenhouse effect modified the water cycle over different regions and continents?
  ....
- Water management influences:
  To what extent do water management practices and land use change (e.g., deforestation) modify the water cycle on regional to global scales?
  ....
- Variability and trends of water availability:
  How do water & land use and climate change affect the variability (including extremes) of the regional and continental water cycle?