Topological Characterization and Uncertainty Visualization of Atmospheric Rivers

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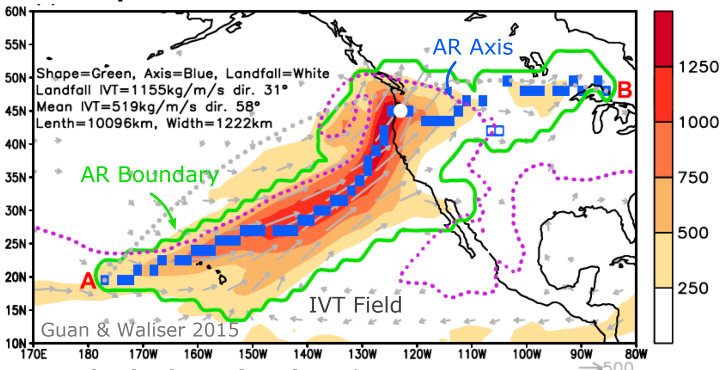
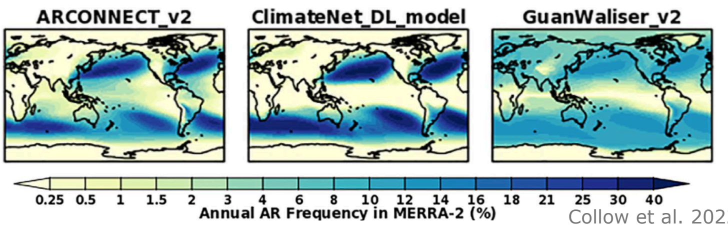
1. Atmospheric Rivers



Atmospheric rivers (ARs) are long, narrow regions of water vapor in the Earth's atmosphere that transport heat and moisture from the tropics to the mid-latitudes. ARs are often associated with extreme weather events in North America. However, characterizing ARs has been a challenge due to the lack of a universal definition. One common quantity used to define ARs is the **Integrated Vapor Transport (IVT)** field calculated from a combination of water vapor and wind. Existing AR detection tools (ARDTs) produce distinct AR boundaries for the same event, see example below, making the risk assessment of ARs a difficult task.



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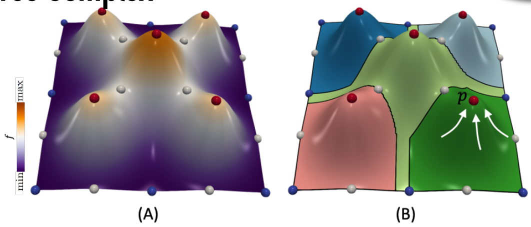
Our goal is to visualize the uncertainties associated with an ensemble of ARs identified by a set of ARDTs. We propose an **uncertainty visualization** framework inspired by *MetroSets* [1]. Our framework consists of three steps:

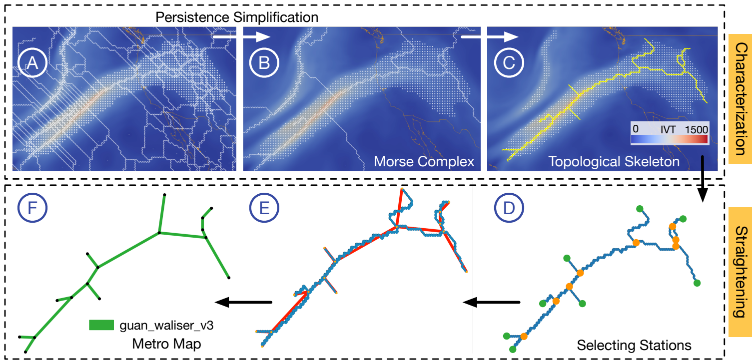
1. *Characterization.* We summarize the interior structure of an AR region by computing the Morse complex of its underlying IVT field, referred to as the **topological skeletons** of ARs, see above (C).
2. *Straightening*. We further simplify the topological skeleton of an AR to a graph with straight edges between selected nodes. We create a **metro map** representation for each AR, see above (F).
3. *Uncertainty Visualization*. Given an ensemble of ARs in the same region at the same time step, we compute a metro map for each member. We overlay the metro maps and shift them strategically to reveal all edges.

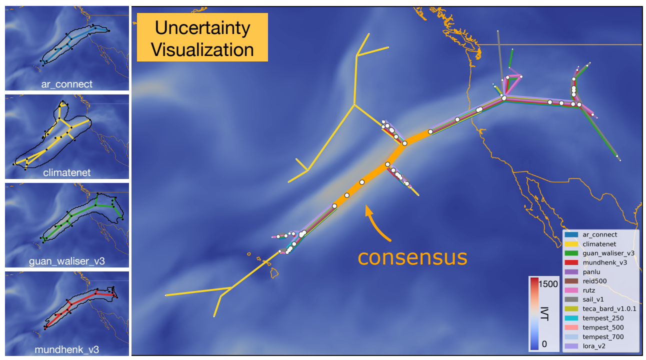
2. Morse Complex



Let f be a continuous function defined on a 2D manifold, see (A). A Morse Complex, see (B), decomposes the domain into segments based on its gradient behavior, capturing connections between maximum, minimum and saddle points. In our setting, we compute the the **Morse complex of an IVT field** defined on a 2D domain, which is formed by the local maxima and saddles connections.

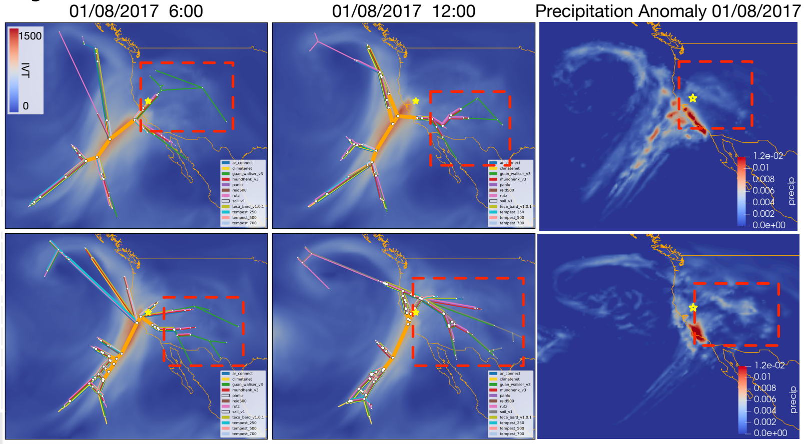
3. MetroSets Uncertainty Visualization





4. Case Study – Jan 7-9, 2017

We show how MetroSets inform scientists about AR impact. The yellow star marks the location of Sacramento. In the four consecutive time steps, the core section of the AR in orange continuously move toward the Sacramento direction. Apart from the high impact on the costal region, Sacramento is located exactly in the inland region of high precipitation anomaly. Additionally, the MetroSets highlights that the ARDT `guan_waliser_v3` (drawn in green) consistently captures the moisture with further land penetration, indicated by the red boxes. This information could be useful for scientists studying inland AR activities in states such as Utah and Colorado.



[1] Jacobsen B., Wallinger M., Kobourov S., Nollenburg M.: MetroSets: visualizing sets as metro maps. *IEEE TVCG*.

Acknowledgement:
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