A Lagrangian Moisture Source and Attribution Model for Southern Africa

or

"Where does all the water come from?"

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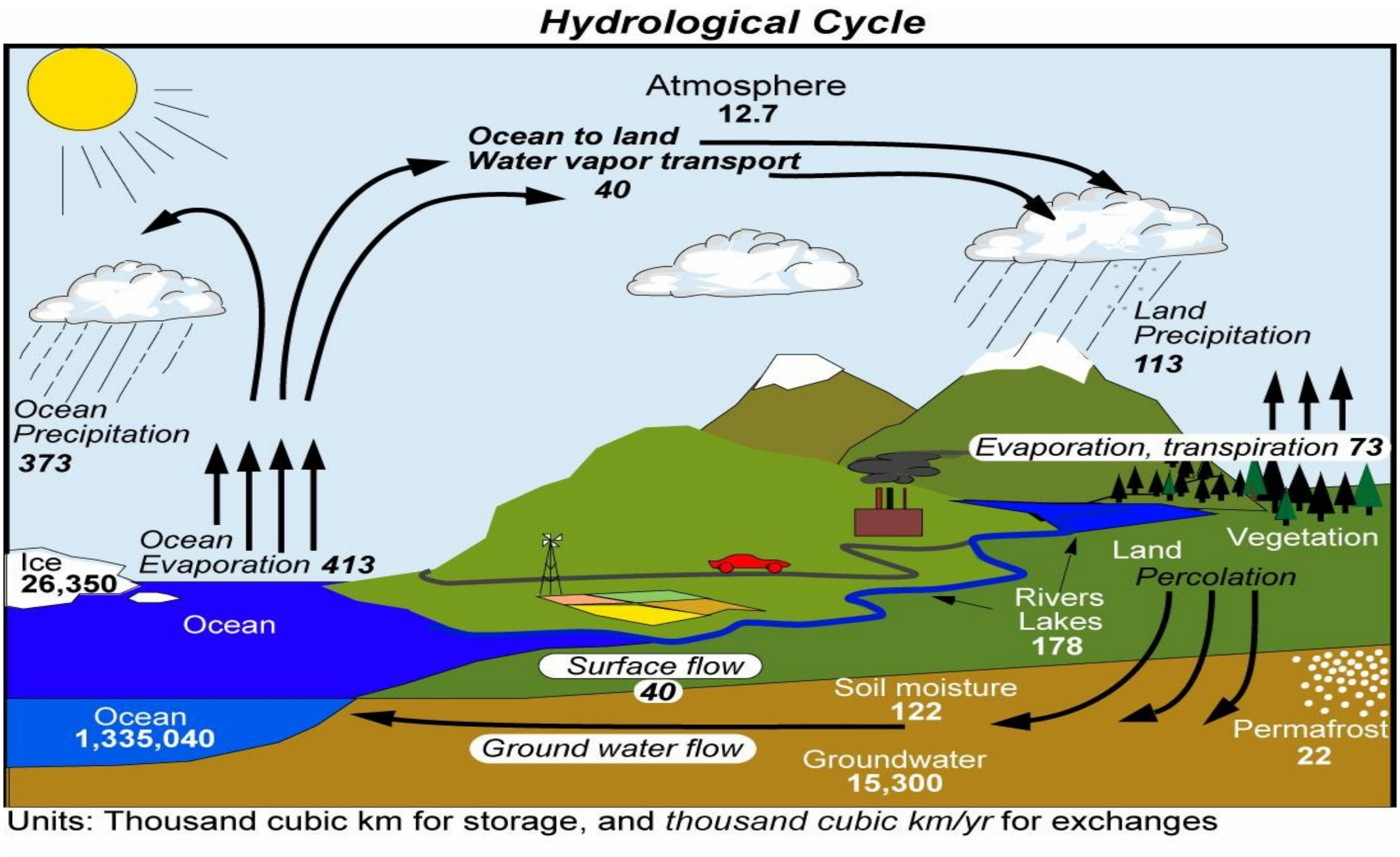
The hydrological cycle: Where, how, how much?



Background

Precipitation is arguably the most important climate parameter for much of sub-Saharan Africa

… and yet our understanding of the regional dynamics of moisture and rainfall is still poor

Precipitation has two prerequisites:

- The presence of sufficient atmospheric moisture
- A source of uplift (circulation, orography, convection)

So the question is, for any precipitation event:
Where did the water evaporate from?
Which sources are most "important"?
What circulation sequencing moved it to the event?

Existing approaches

Sensitivity studies

Run control and perturbed simulations and evaluate the model sensitivity

- Ocean sources:
  Increase/decrease SSTs in a region (where?) and evaluate model response
- Land surface source
  Force soil moisture or initialize with perturbed soil moisture
  (New, Hewitson, Jack and Washington, CLIVAR Exchanges 2003)

BUT

•We have to pre-suppose where the source region might be and it has to stay the same under all synoptic conditions

•Perturbations influence both circulation and moisture, how do we disaggregate?

Existing approaches

Moisture source diagnosis

Direct techniques: Collected rainwater isotope analysis (Gat and Matsui 1991)
- Not dependent on model fields, direct observation
- Limited by observations and resolution
- Doesn't reveal pathways or circulation dynamics

Time mean, vertically integrated, moisture flux and flux divergence
- Time meaning hides high frequency dynamics (synoptic event sequencing)
- Vertically integrated or particular levels (which ones?)

Model water vapor tracers (Koster et al. 1986, Bosilovich and Schubert 2002)
- Requires pre-specifying source regions
- Inline running requires modification of model code

Bulk water balance methods (recycling analysis, many variations):
- Works well for large scale climate means but can't really handle events
- Assumptions of complete mixing and linear flow

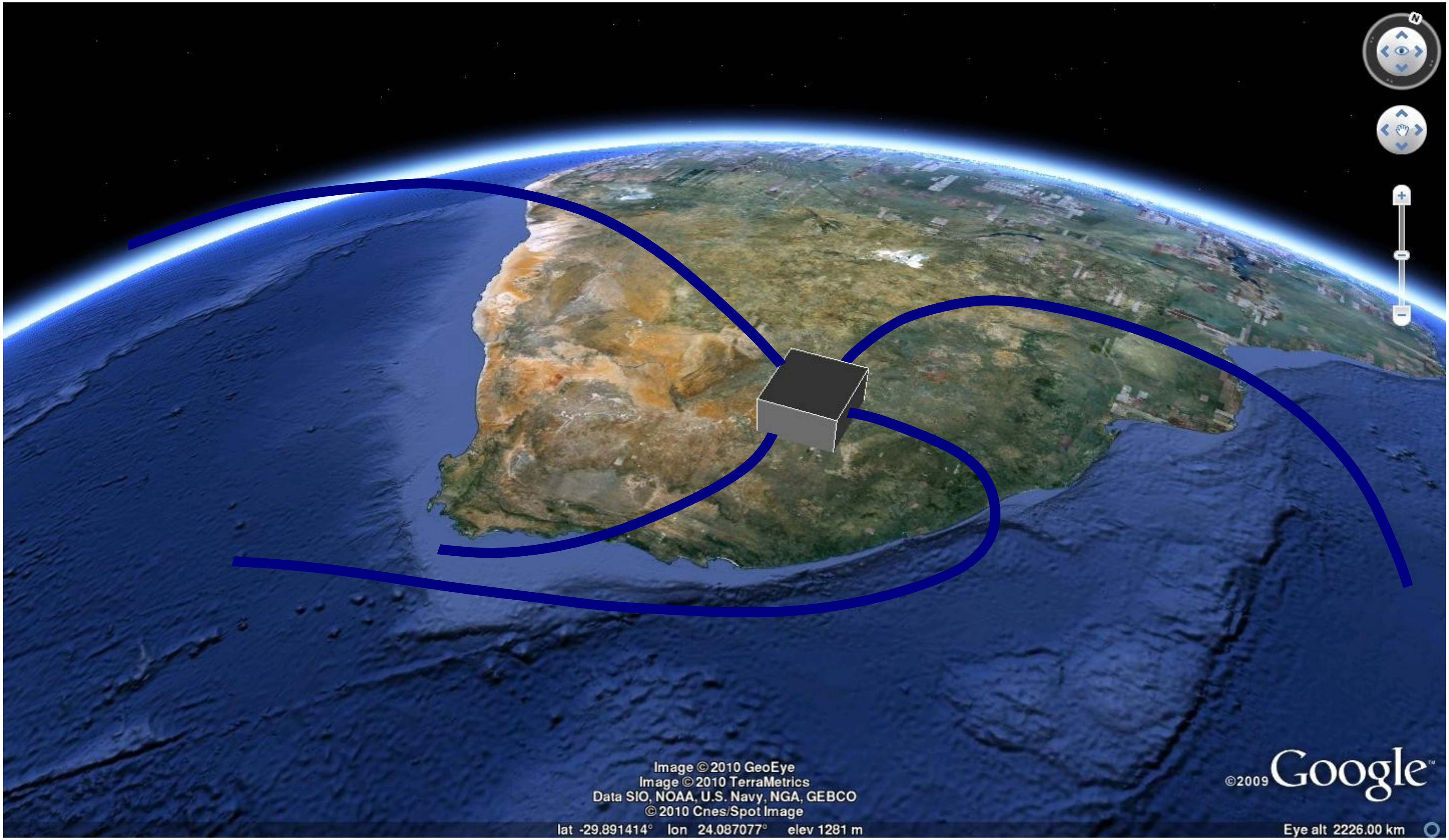
A quick aside: CORDEX?

Coordinated Regional Downscaling Experiment

- Multiple CMIP5 GCMs driving multiple RCMs to form a matrix of regional downscaling data sets

- Exploring and evaluating regional moisture balances and dynamics provides important insights into model performance and diagnosis of problems and differences between models

A Lagrangian moisture source model



A Lagrangian moisture source model: trajectory genesis

Developed to be forced by RCM output fields (offline)

Time reversed trajectories (more efficient)

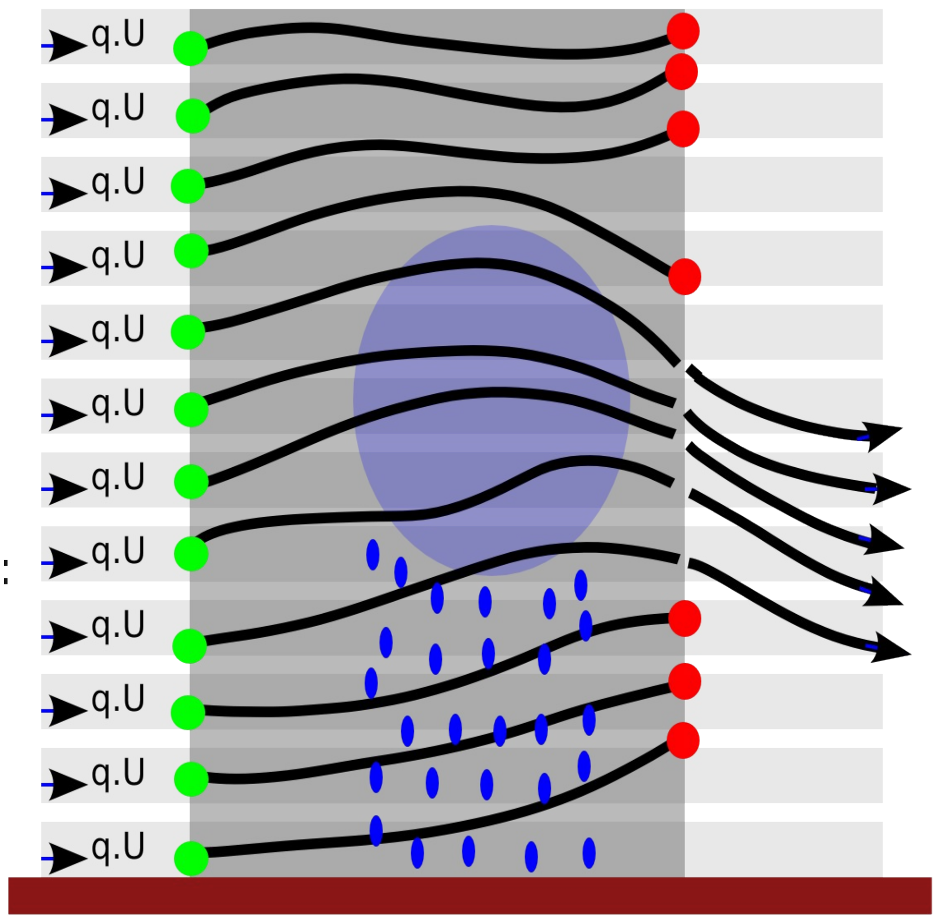
Specify a **target domain**

Represent full moisture flux into a target domain as trajectory parcels

Parcel moisture changes accumulated

Filter trajectories on exiting target domain:

> 5% moisture change
RCM precipitation
RCM rain liquid water

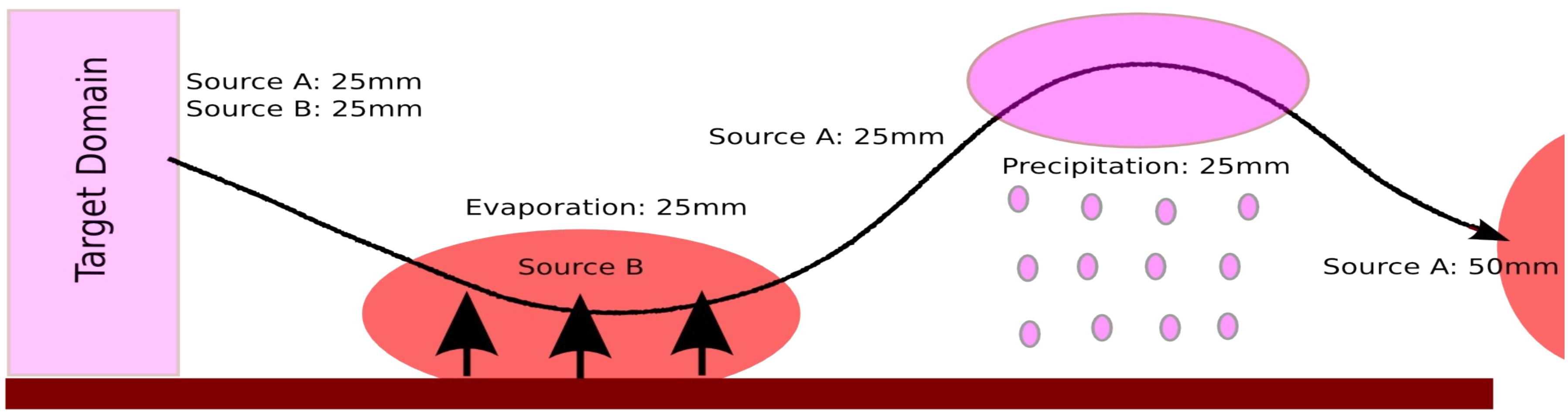


A Lagrangian moisture source model: ppt/evap diagnosis

Precipitative losses and evaporative gains diagnosed at each time step (15 min):

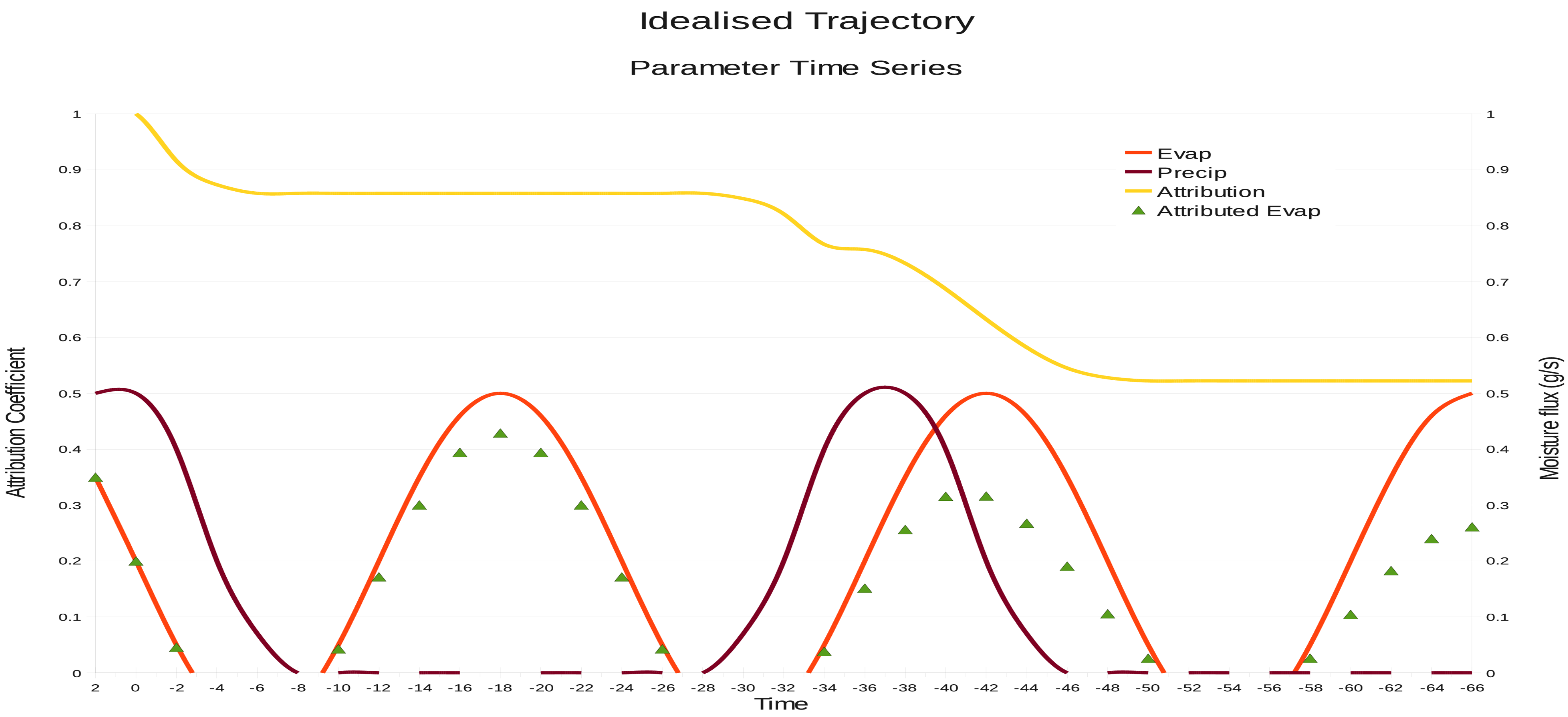
Precipitation: change in moisture > 1%
RCM precipitation > 0.2mm / day
RCM rain liquid water > 0

Evaporation: change in moisture > 1%
Altitude < top of PBL



A Lagrangian moisture source model: source attribution

The attribution coefficient captures the reduction in contribution of upstream evaporative source caused by losses to precipitation events en-route



Some challenges

Trajectory integration errors

Higher spatial resolution (RCM) and temporal resolution (1 hourly) fields required for reasonable trajectory accuracy

Precipitation and evaporation diagnosis

Interpolation and trajectory errors produce spurious moisture changes
Filtering produces an underestimated diagnosis of precipitation

Convection, convection, convection...

Not represented in model output fields
Produce moisture profile changes that cannot be diagnosed offline

For climate system analysis, vulnerable to model error
(model climate not real climate!)

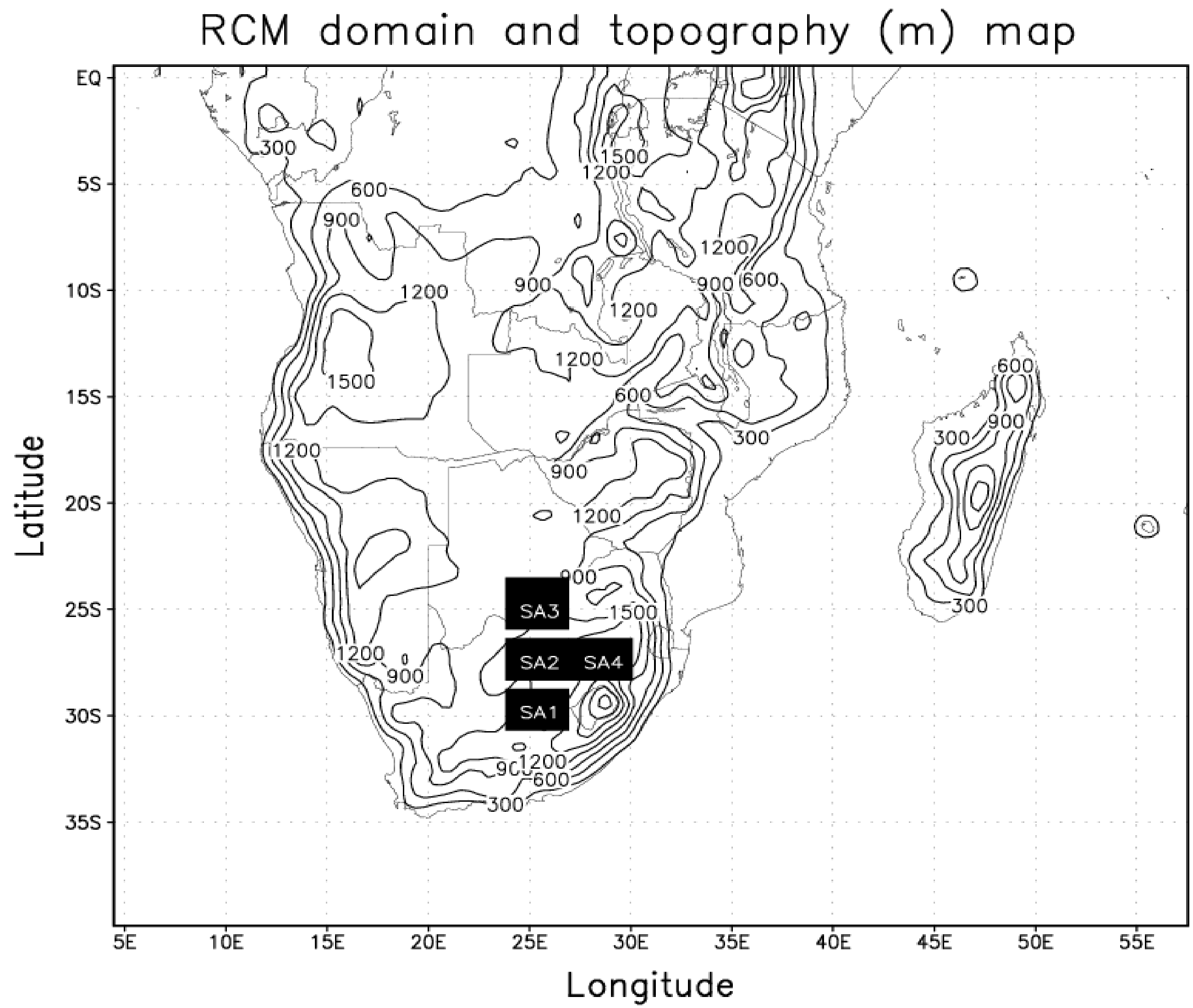
Two summer season experiment

RCM driving simulation

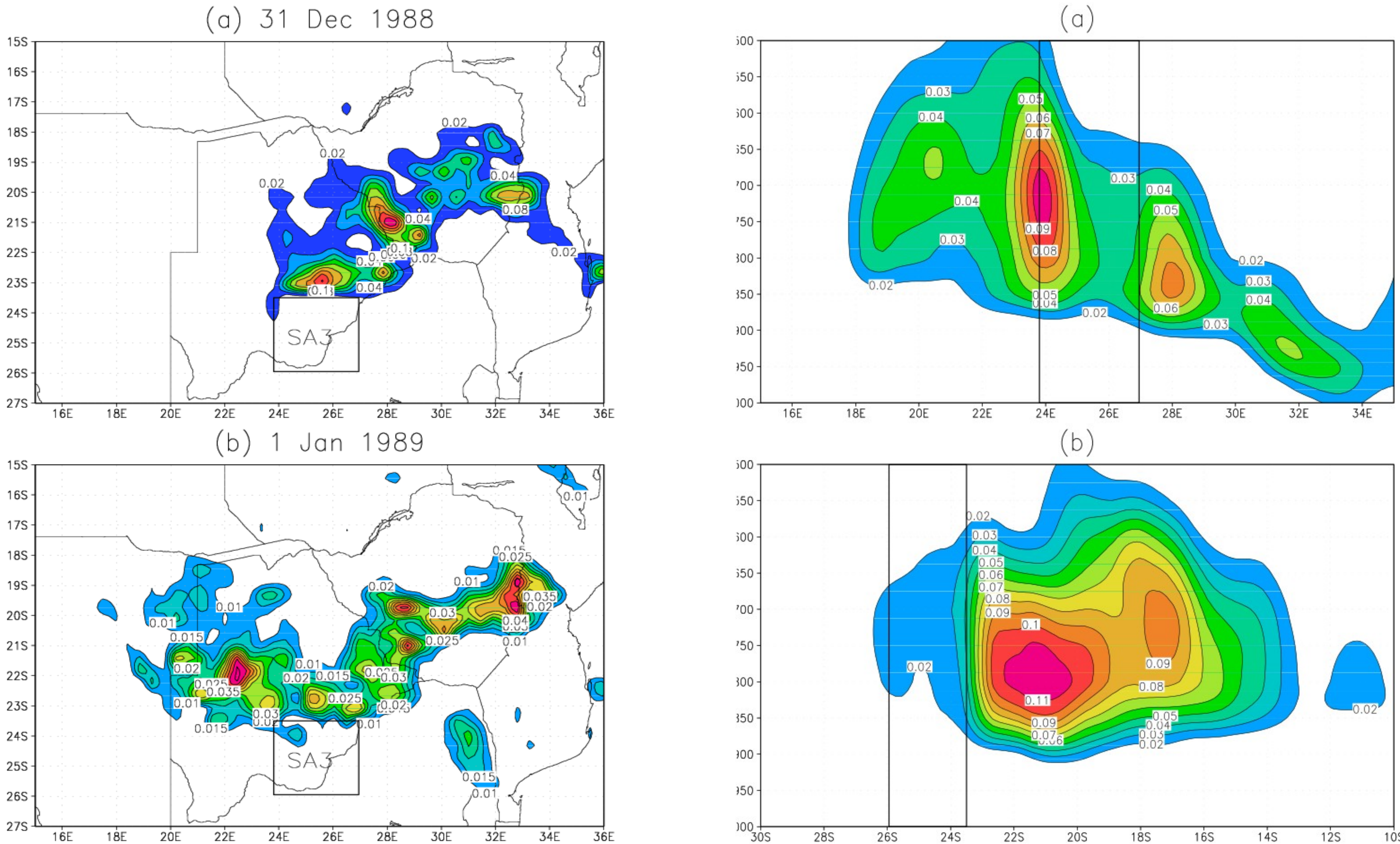
MM5 RCM
50 km resolution
1 hour archive interval

Lagrangian model

4 target domains
15 minute trajectory
timestep
4 month integrations
2 seasons
Wet season
Dry season



A single event example from 1988/89 season:



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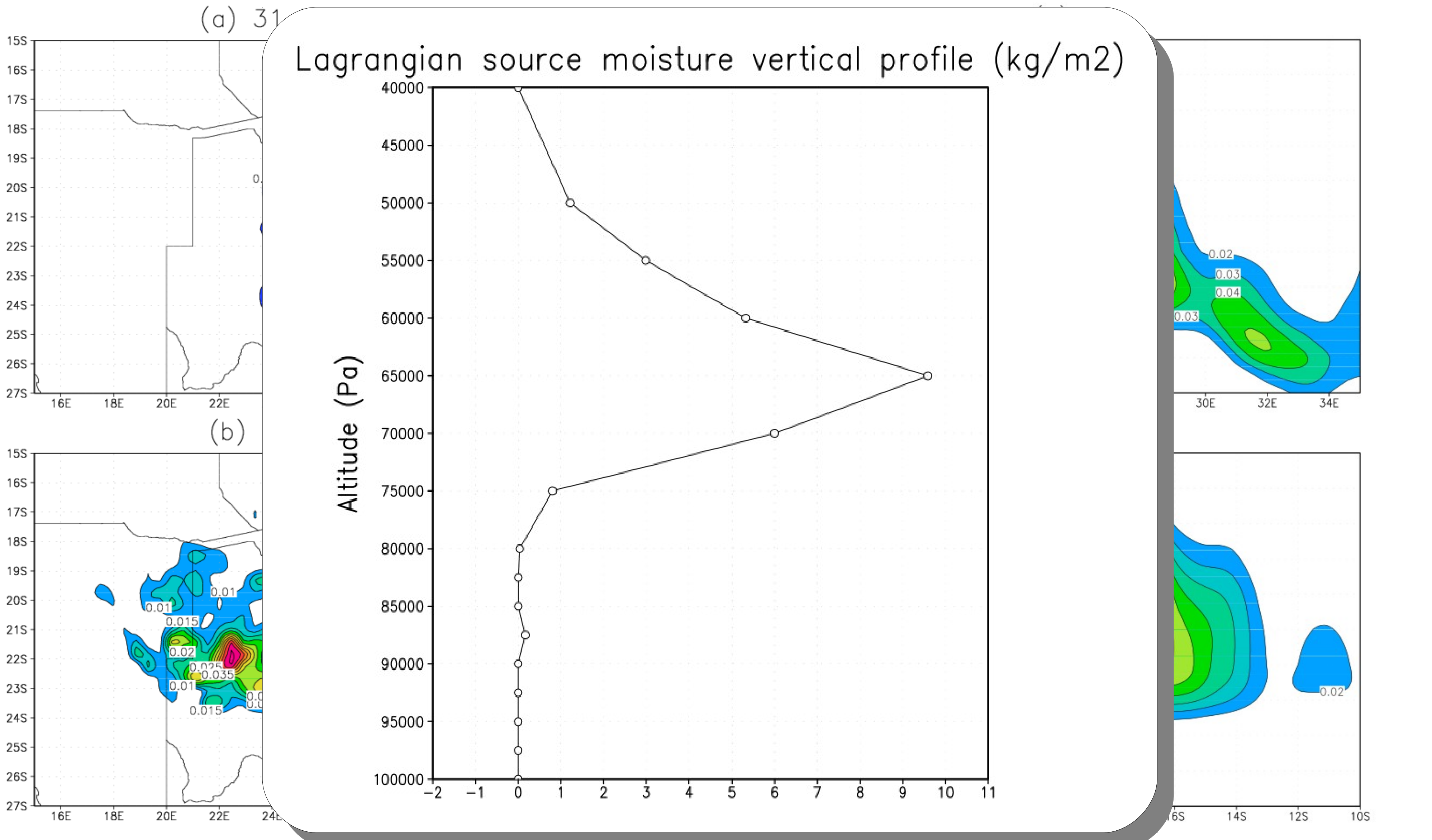


Two summer season experiment: ocean 1988/89

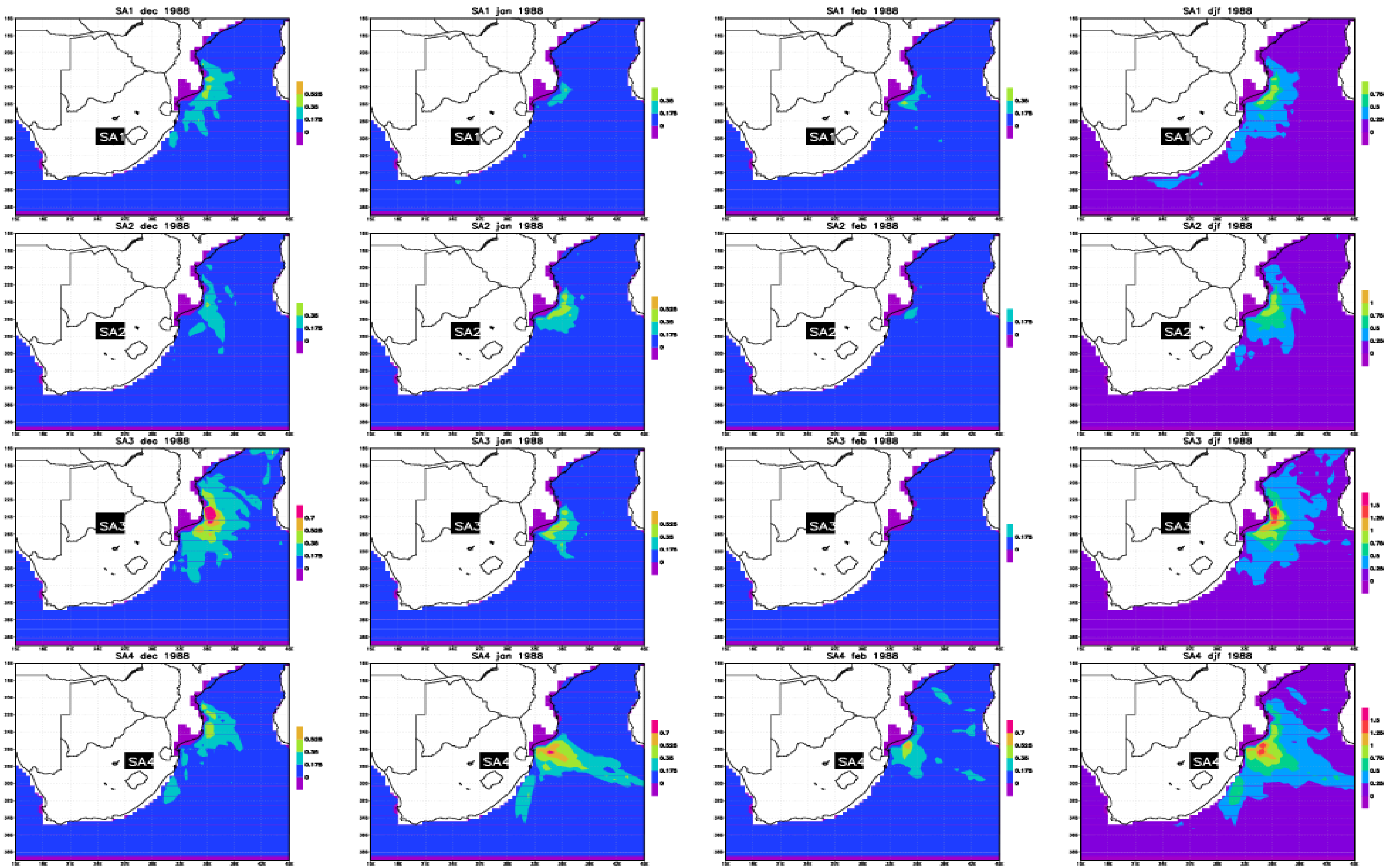
December	January	February	DJF

D1

D2

D3

D4



Two summer season experiment: land surface 1988/89

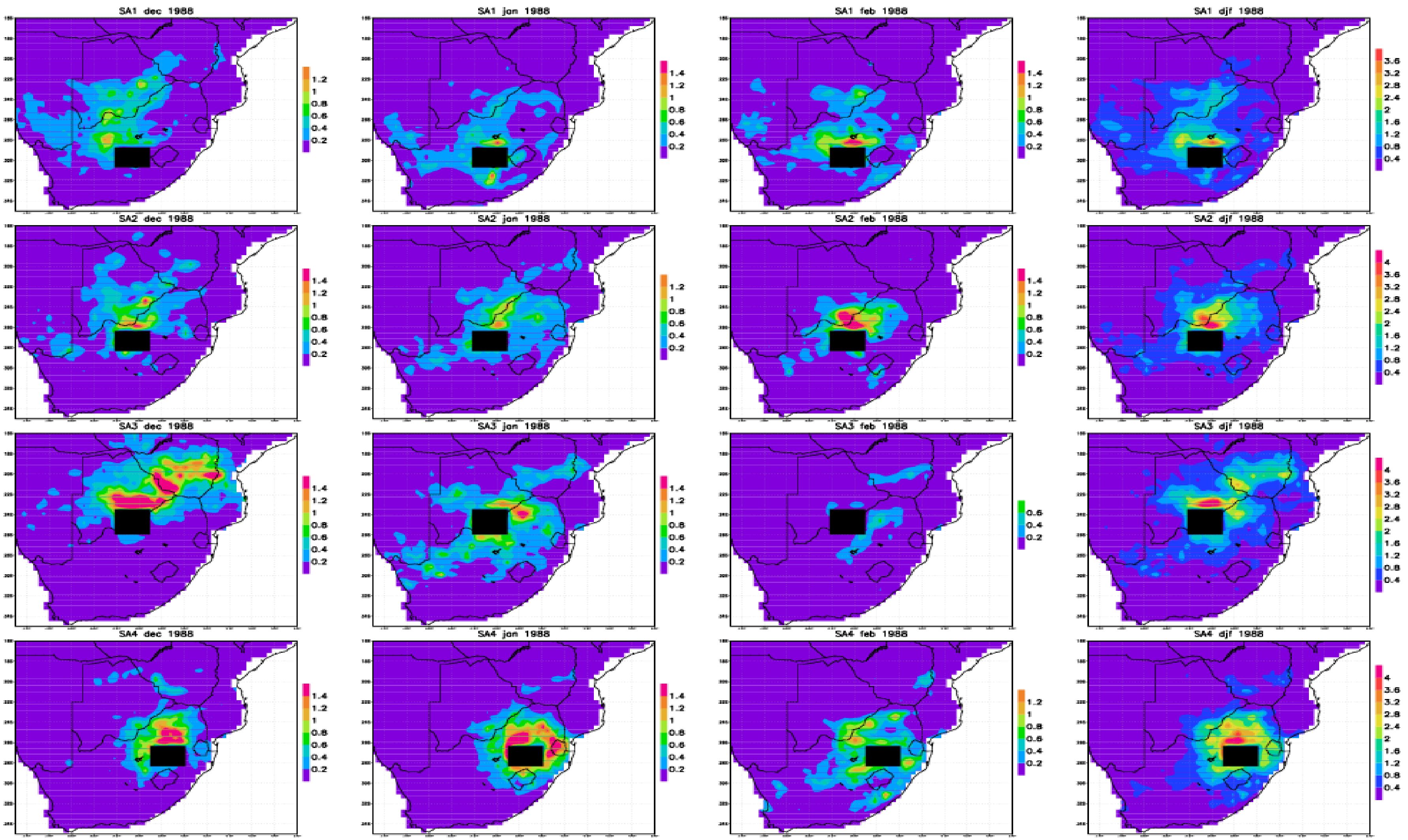
December January February DJF

D1

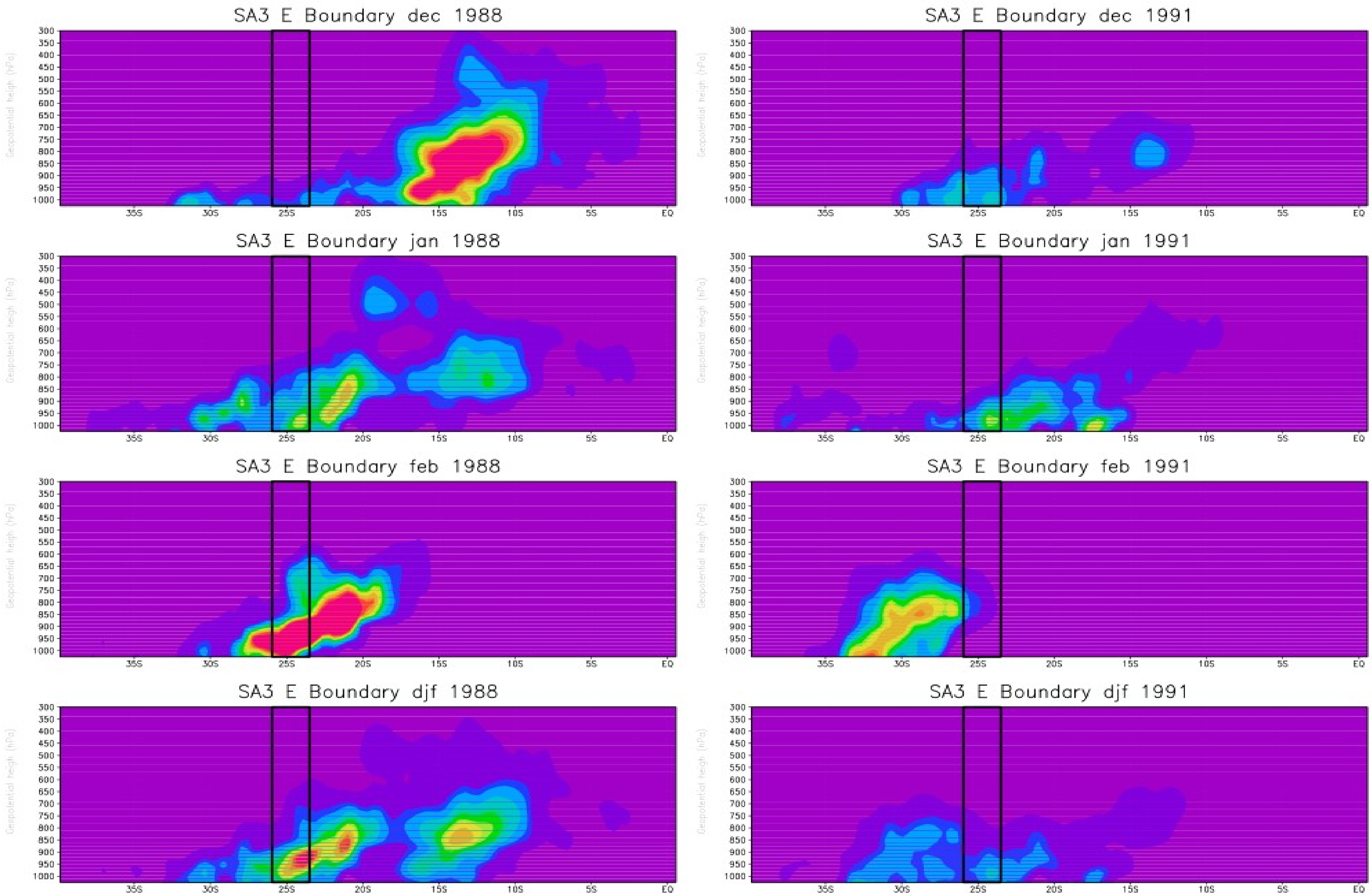
D2

D3

D4



Two summer season experiment: Eastern boundary source



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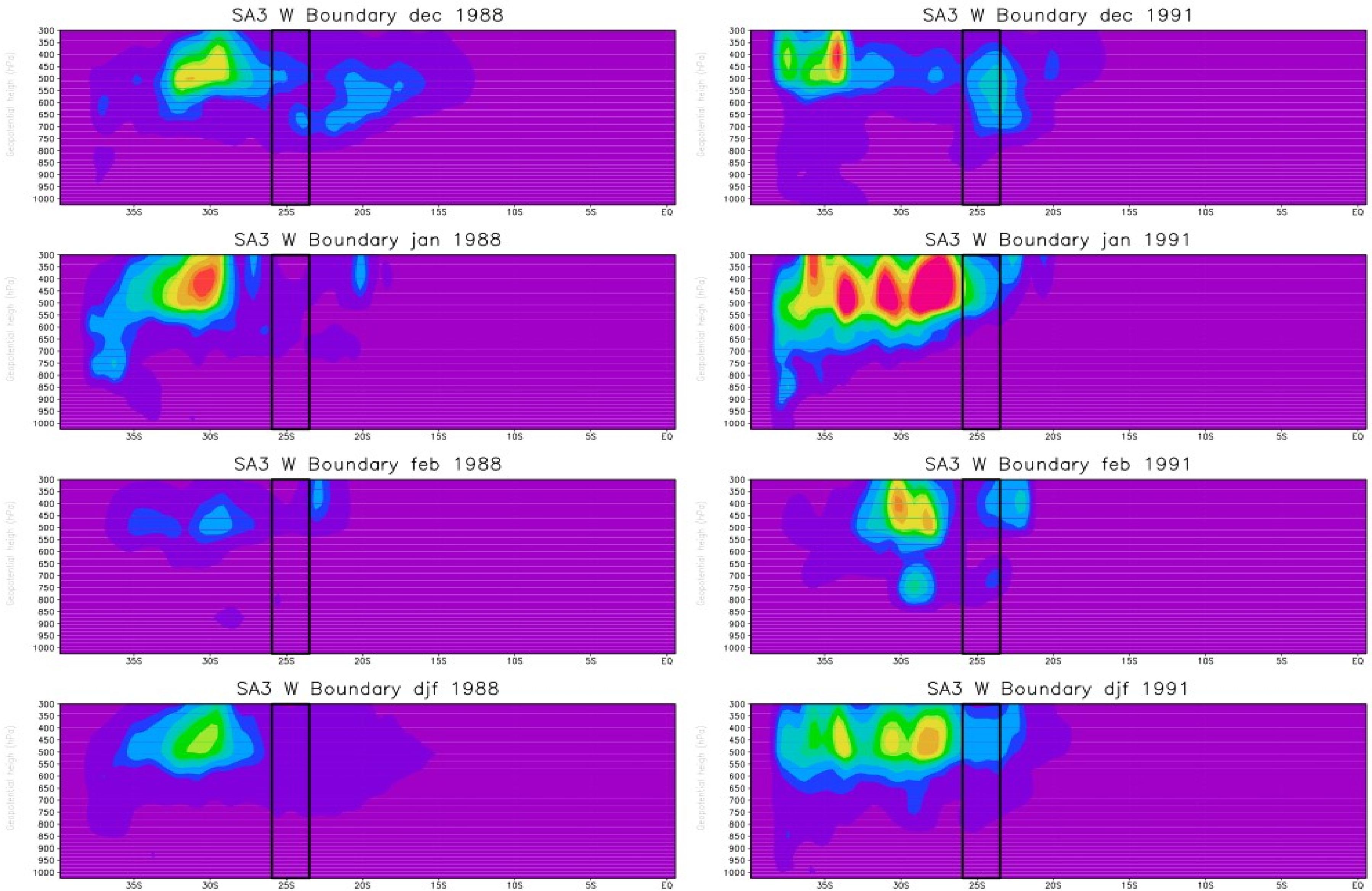
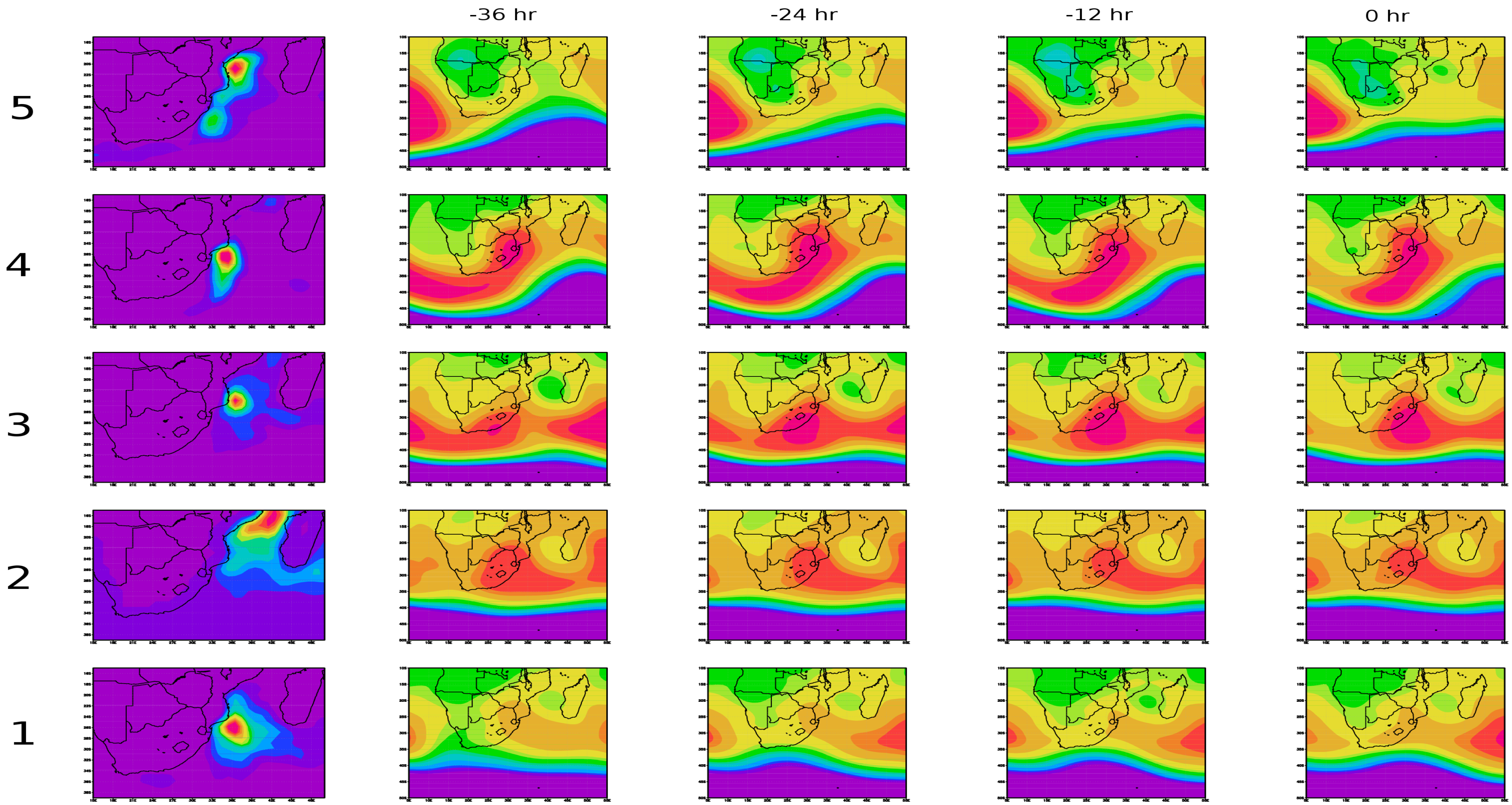


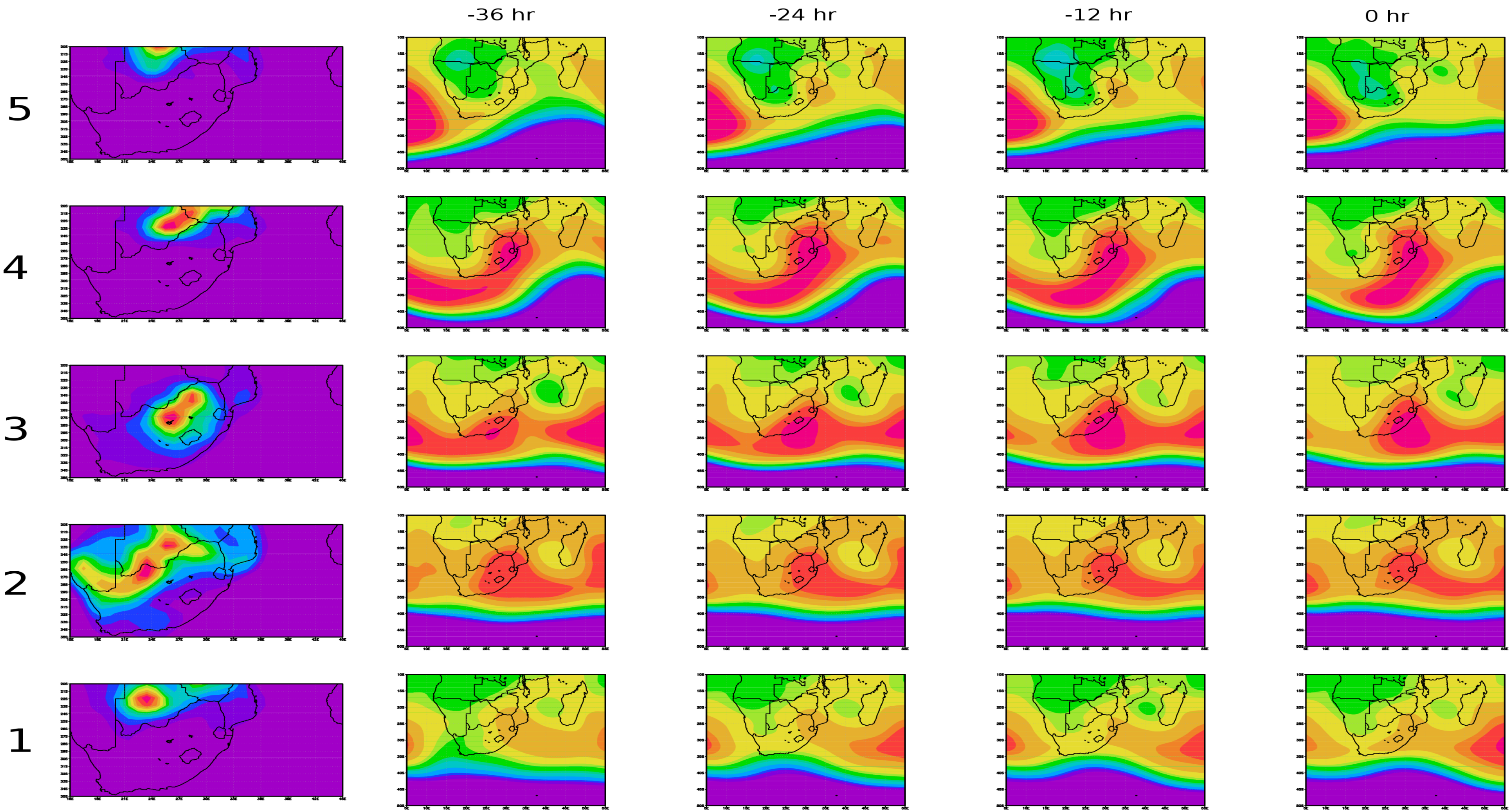
Two summer season experiment: attribution summaries

SA1	Land	Ocean	North	South	West	East	Total
Dec	29 (38%)	11 (15%)	2 (3%)	11 (15%)	18 (24%)	4 (5%)	76
Jan	21 (40%)	7 (14%)	1 (1%)	10 (20%)	10 (20%)	3 (6%)	53
Feb	25 (35%)	10 (13%)	2 (2%)	14 (19%)	16 (22%)	6 (9%)	72
SA2	Land	Ocean	North	South	West	East	Total
Dec	29 (41%)	11 (15%)	5 (7%)	7 (9%)	13 (18%)	7 (9%)	72
Jan	25 (39%)	12 (18%)	1 (2%)	8 (13%)	9 (14%)	9 (14%)	63
Feb	21 (39%)	7 (13%)	2 (3%)	8 (14%)	10 (18%)	7 (12%)	54
SA3	Land	Ocean	North	South	West	East	Total
Dec	51 (40%)	23 (18%)	14 (11%)	11 (8%)	11 (9%)	18 (14%)	128
Jan	34 (41%)	13 (15%)	4 (5%)	8 (10%)	11 (13%)	13 (16%)	84
Feb	10 (26%)	5 (13%)	1 (4%)	4 (10%)	3 (9%)	15 (39%)	38
SA4	Land	Ocean	North	South	West	East	Total
Dec	25 (38%)	12 (18%)	3 (4%)	11 (16%)	11 (17%)	5 (8%)	67
Jan	30 (37%)	17 (21%)	1 (1%)	13 (15%)	7 (9%)	13 (16%)	81
Feb	26 (36%)	14 (19%)	2 (3%)	11 (15%)	4 (6%)	16 (22%)	73

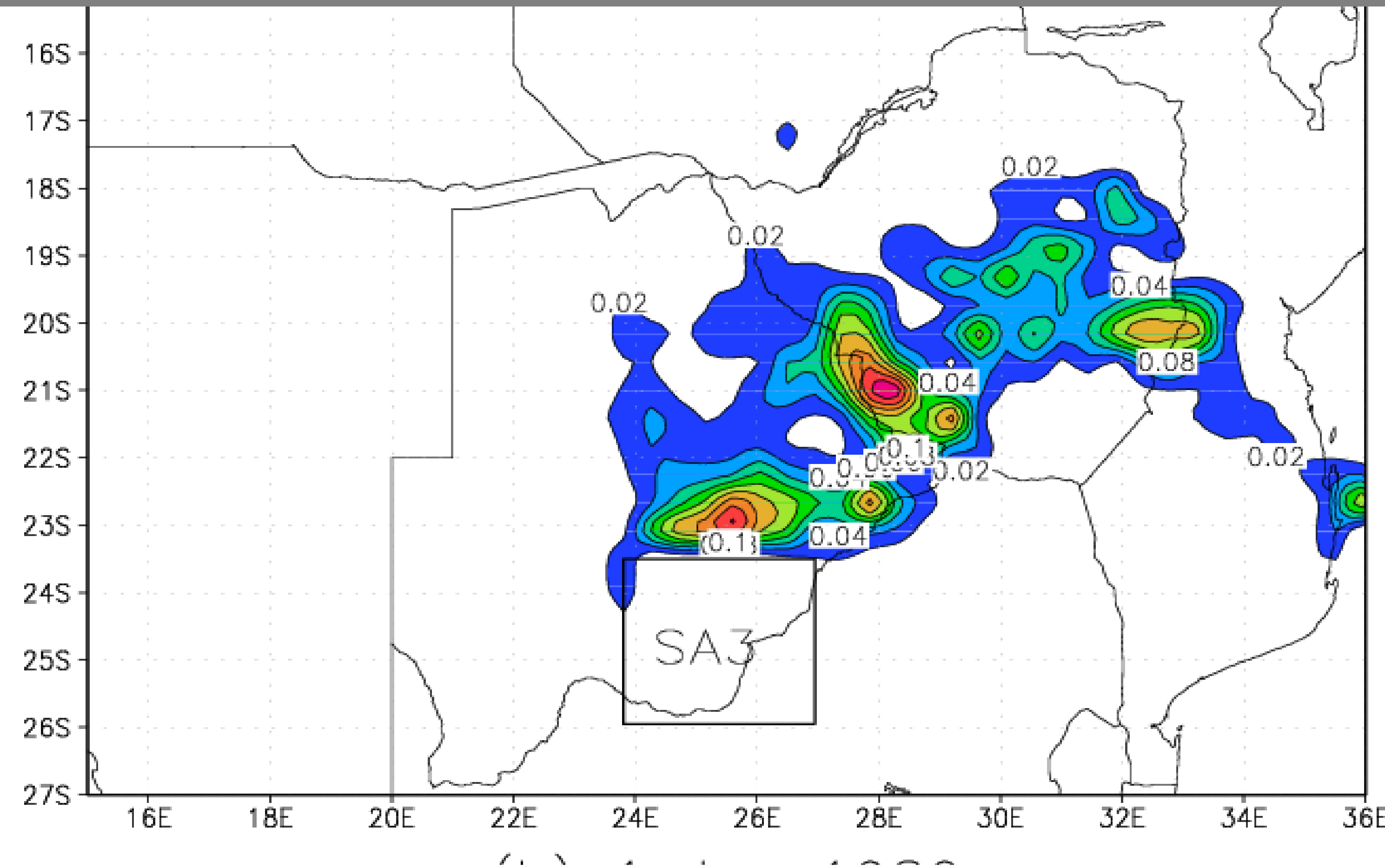
Two summer season experiment: ocean with synoptics



Two summer season experiment: land with circulation



Seasonal results: A leap frog mechanism?



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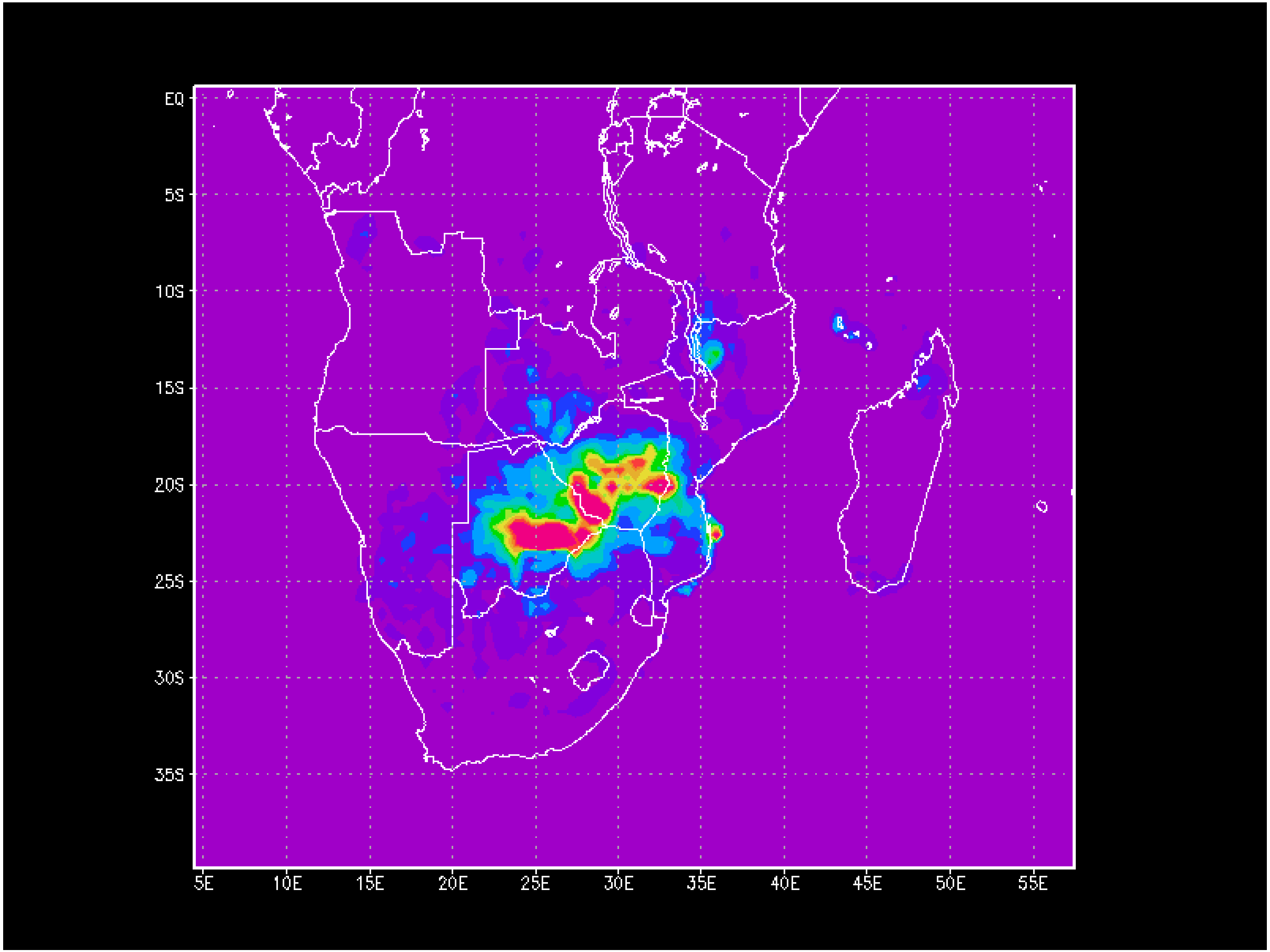

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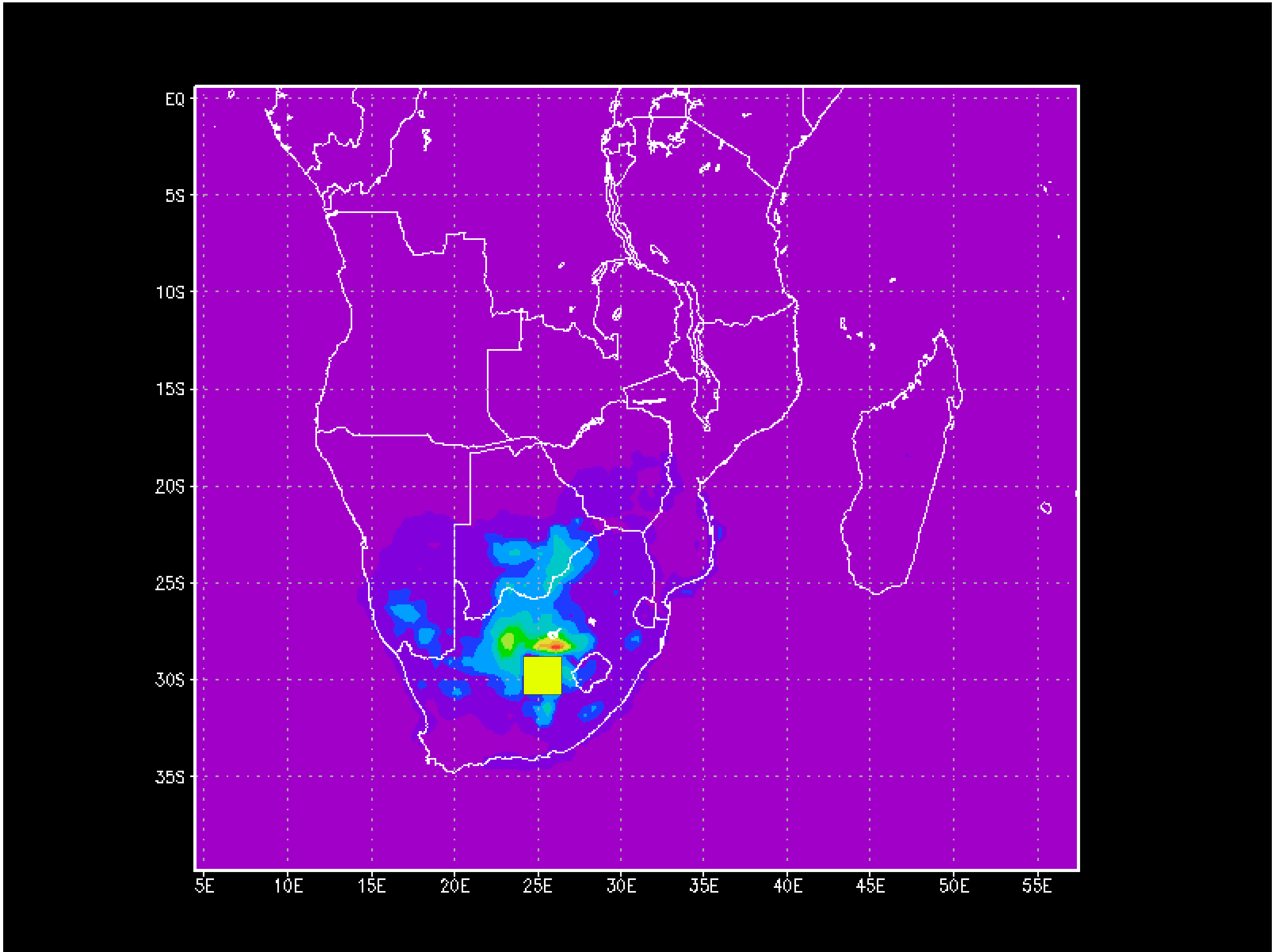

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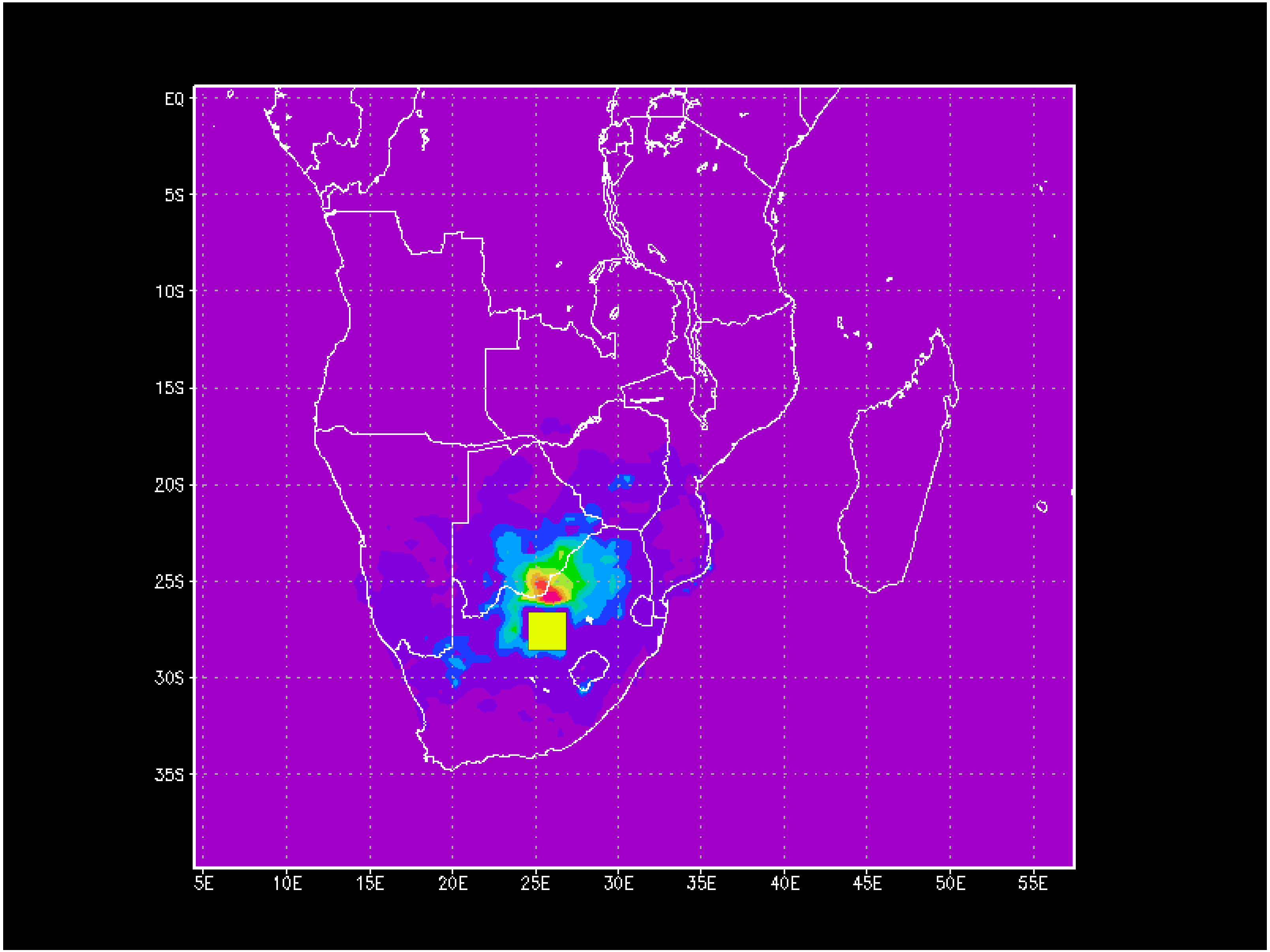

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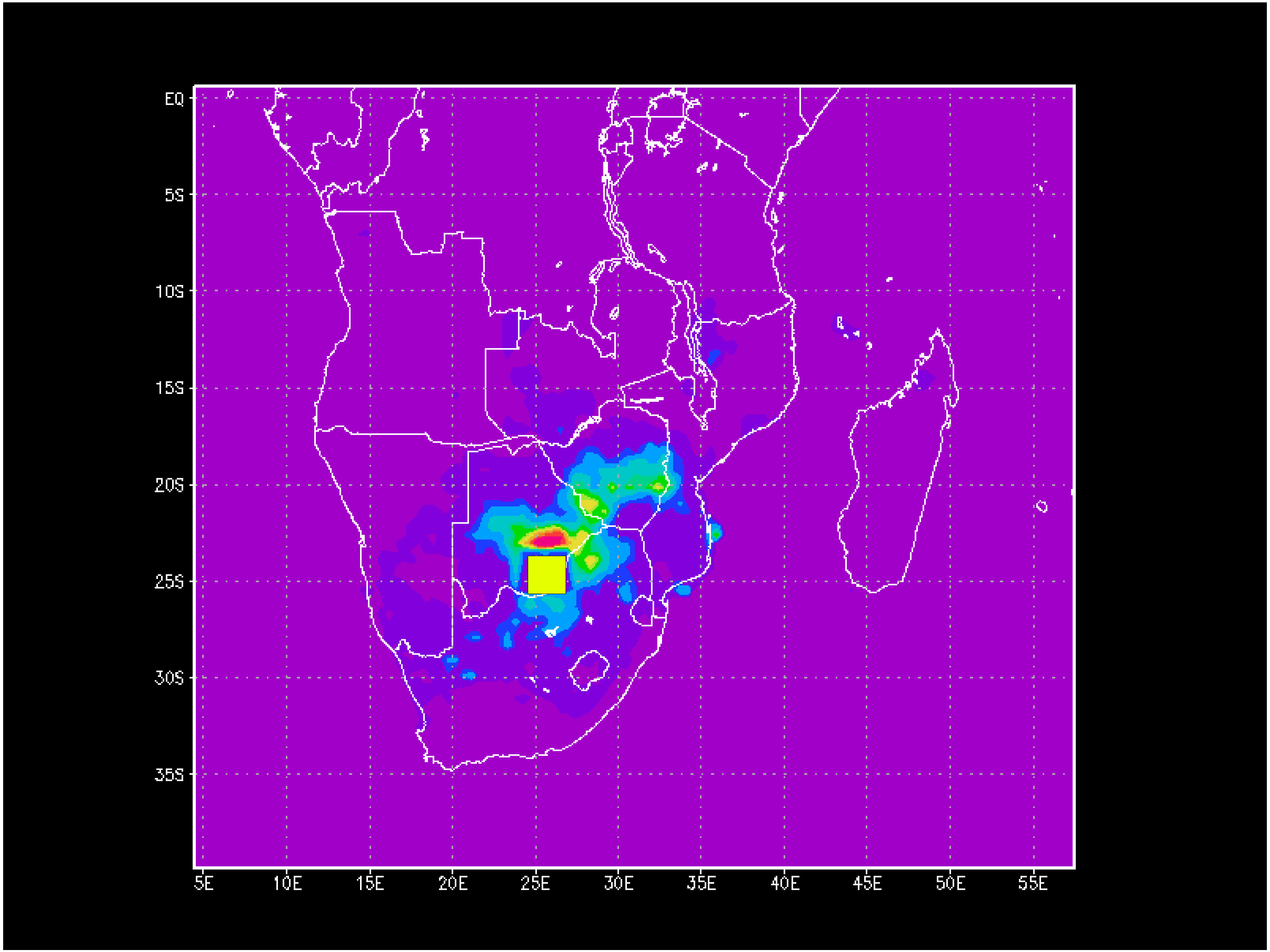

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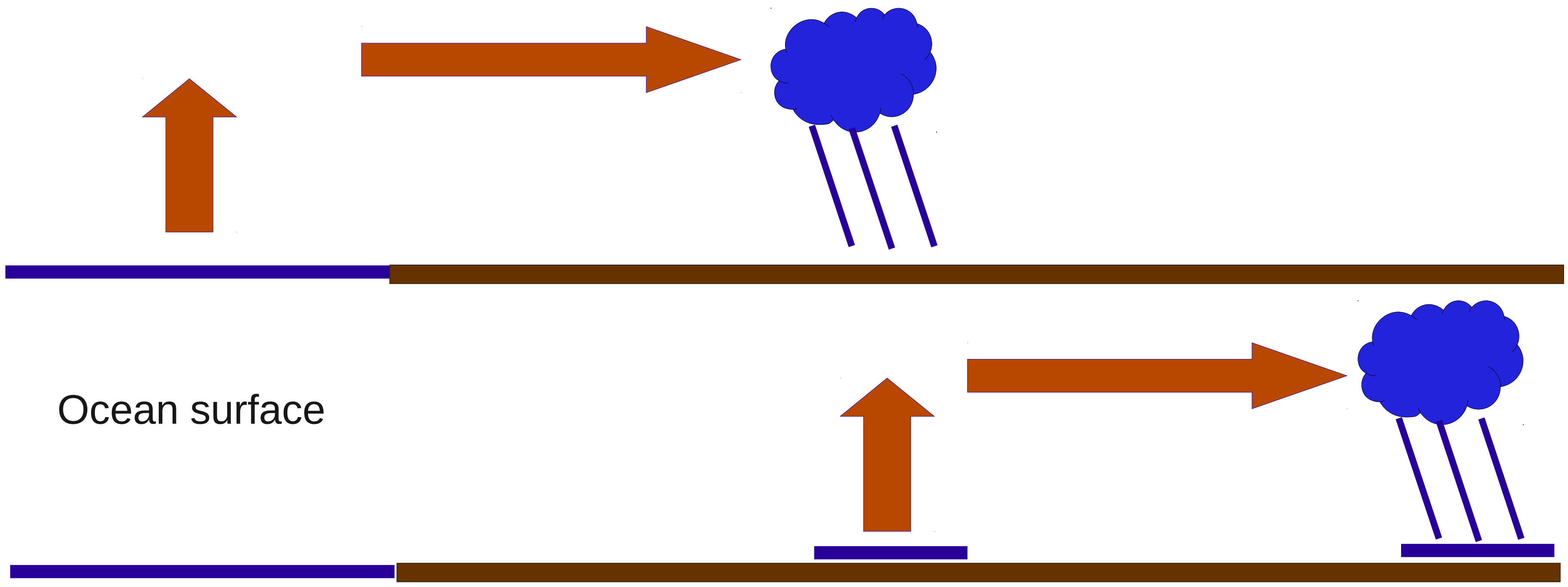

Moisture is indeed (of course) ocean sourced but perhaps not directly
Mode of “advection” includes precip/evaporation cycles
What is the role of land surface characteristics?
Precipitations events potentially strongly related to prior events?
What about interactions with synoptic sequencing?

Conclusions and future

The methodology

- Seems to produce reasonable results though validation is difficult
- Provides some very useful insights into the simulated climate moisture dynamics
- A useful RCM diagnosis and inter-comparison tool?

The results

- Suggests moisture source dynamics and moisture transport in the region includes a significant regional, land surface, component rather than just remote

- Point towards more targeted and detailed sensitivity studies

Future

- Drive with cloud resolving model in order to avoid convection limitations
- Develop diagnostics tailored to exploring leap-frog moisture transport dynamics