Potential for wind tracing from 4D-Var assimilation of aerosols and moisture

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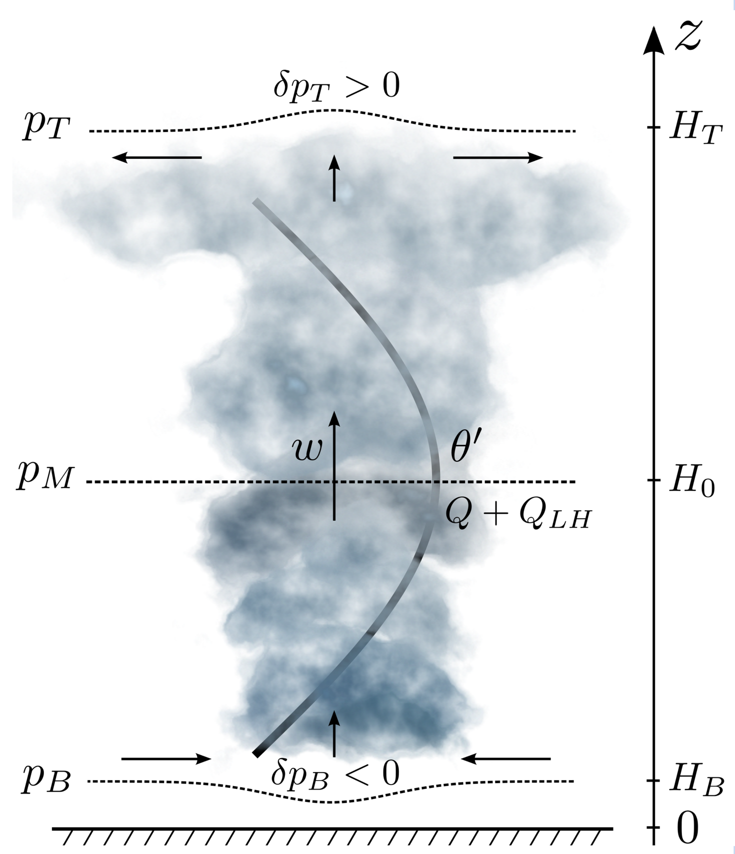
1 Motivation

We present a new model of intermediate complexity for studying non-linear couplings between Moisture, Aerosol and Dynamical variables (MAD model).
The MAD forecasting system has an accompanying Data Assimilation Model (DAM) including a tangent-linear and adjoint model for 4D-Var data assimilation.
MADDAM data assimilation and forecasting system is applied for the tropical atmosphere using the background-error covariance matrix including the mass-wind coupling of the equatorial waves.

We present the MADDAM system and apply it to study the potential of 4D-Var to retrieve wind-field information from the observations of aerosols and moisture in the tropical atmosphere. In particular, we discuss the wind retrieval in the atmosphere near saturation with strong non-linear moist dynamics.

2 Moisture-aerosol-dynamics: MAD model

- Describes dynamical response of the tropical atmosphere to the heat sources
- Main source latent heat release due to condensation, which has approximately half-sinusoidal vertical structure
- Lower layer winds are entering deep convetion, upper layer winds detraining



A model of tropical atmosphere with deep convection following Gill (1980)

Thermodynamic (& continuity) eq.

$$\frac{\partial\theta'}{\partial t} + u\frac{\partial\theta'}{\partial x} + v\frac{\partial\theta'}{\partial y} - \frac{\theta_0 N^2 H_0}{g}\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right) = \frac{L_c}{c_p}\left(\frac{dq}{dt}\right)_s$$

diabatic heating

Momentum equations

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} - \beta y\, v = \frac{gH_0}{\theta_0}\frac{\partial\theta}{\partial x}$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + \beta y\, u = \frac{gH_0}{\theta_0}\frac{\partial\theta}{\partial y}$$

Moisture eqation

$$\frac{\partial q}{\partial t} + \frac{\partial (uq)}{\partial x} + \frac{\partial (vq)}{\partial y} = E - P$$

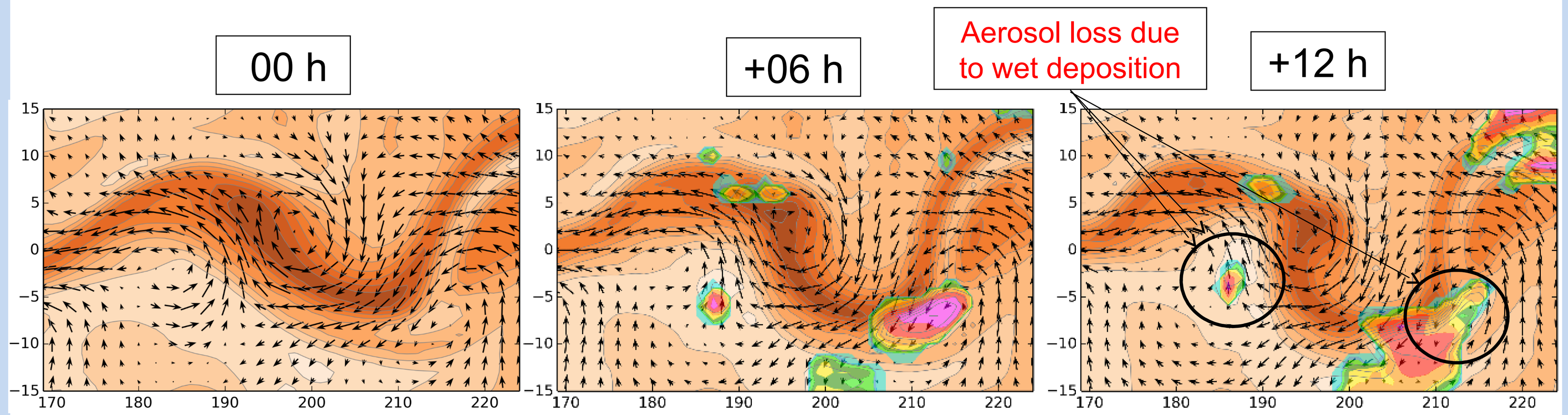
evaporation; precipitation

Tracer equation

$$\frac{\partial c}{\partial t} + \frac{\partial (uc)}{\partial x} + \frac{\partial (vc)}{\partial y} = K_{dif}\nabla^2 c - K_{wd}(cP) - K_{dd}c + S^+ - S^-$$

Wet deposition; Dry deposition; Sources & sinks

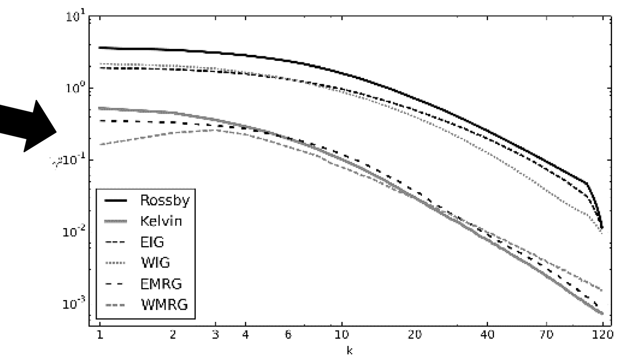
Aerosol-moisture-wind coupling in „MAD“ model

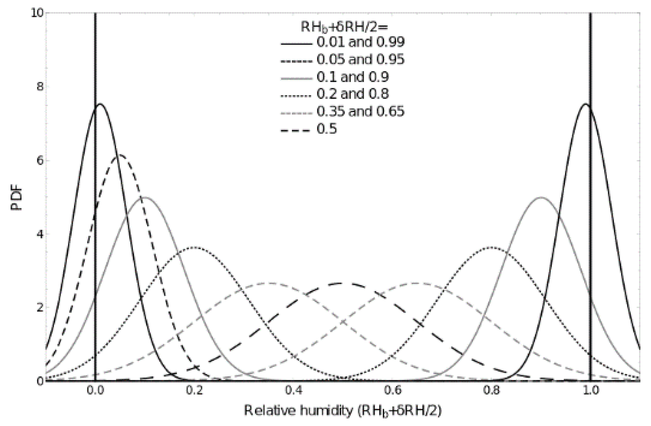


Wavy equatorial easterly jet in the lower troposphere. Moisture convergence leads to condensation, precipitation and latent heat release. Condensational heating increases the saturation humidity. Aerosol is deposited in areas of strong precipitation.

3 MADDAM data assimilation system

- **Incremental 4D-Var** with nonlinear model in outer loop (5 iterations) and TL/AD inner loop minimization (max 20 iterations) using Quasi-Newton method
- **Background error term for dynamics** is built by (assumed uncorrelated) **tropical eigenmodes**. Spectral variance densities derived by MODES from ensebmle data assimilation (EDA) of ECMWF → MULTIVARIATE u, v, θ



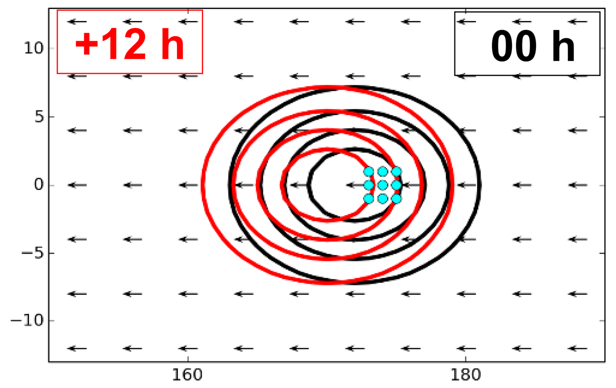


- **Background error term for moisture and aerosols** built by Fourier modes, based on anisotropic SOAR correlation model with Lx=500 km, Ly=200 km → univariate c and multivariate $RH = \frac{q\,p\,R_d}{R_v\, e_s(T(\theta))}$
- Symmetrizing moisture control variable transform $\delta RH^n = \frac{\delta RH}{\sigma(RH_g + \delta RH/2)}$

4 Wind retrieval in dry atmosphere

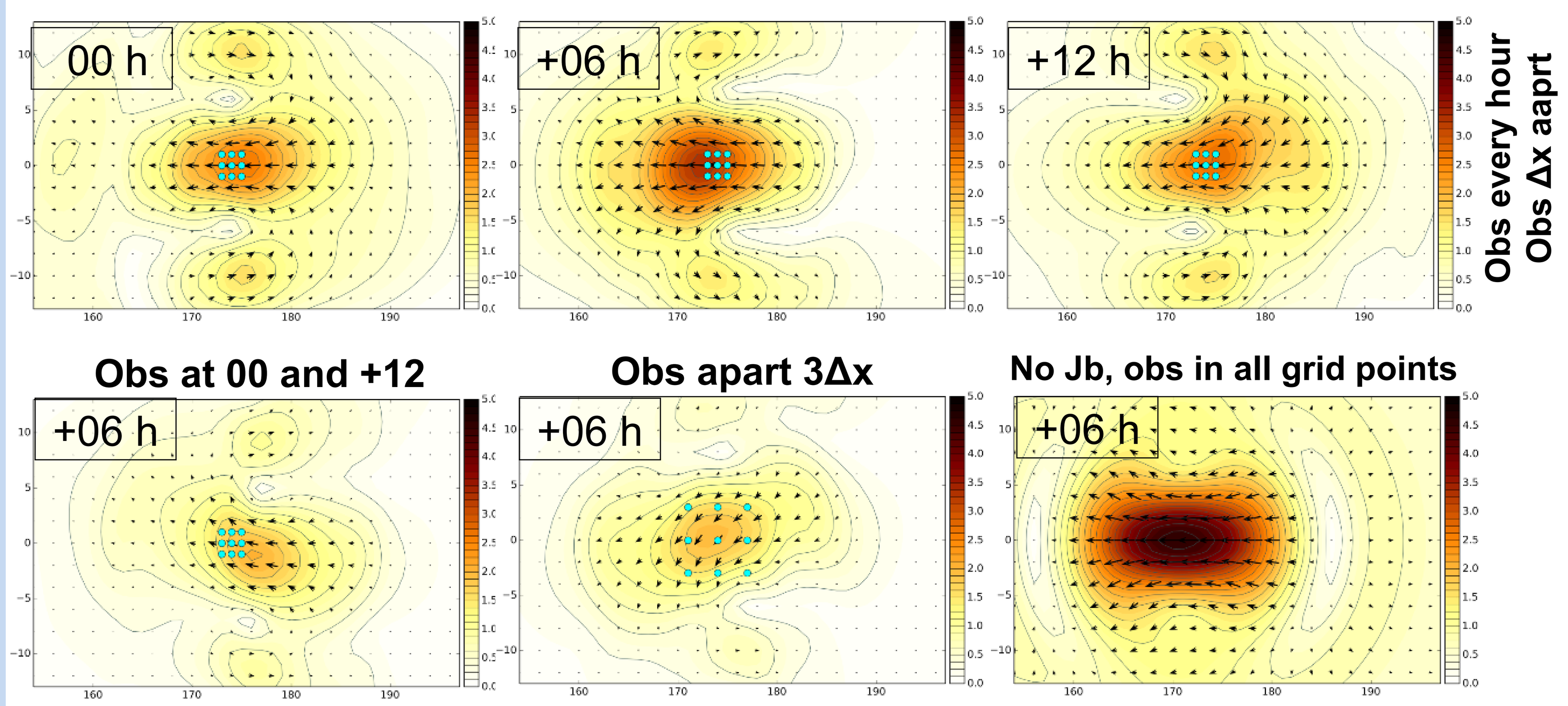
Wind retrieval in homogeneous flow

- OSSE: perfect model, perfect advection
- Nature run: homogeneous easterlies (5 m/s), aerosol cloud (max amp. 5μg/kg)
- 3 x 3 simulated observations of aerosol mixing ratio at equator, one grid point (111 km apart)
- Noisy observations, $\sigma_o = \sigma_b$
- Background: easterlies 1 m/s, mixing ratio 1 μg/kg



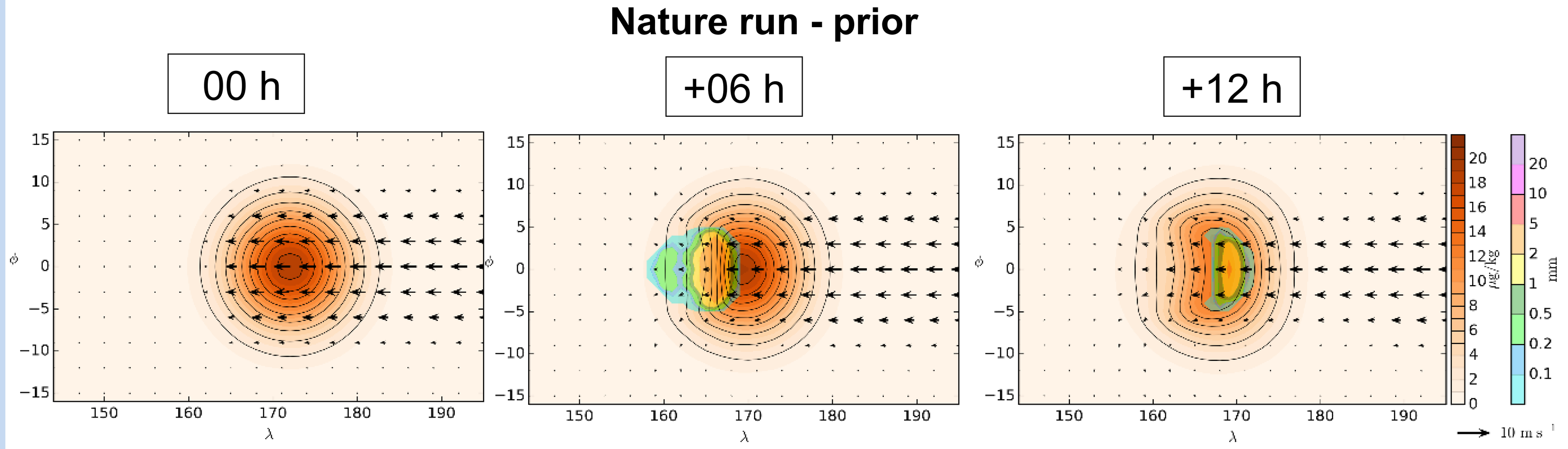
Advection of the aerosol cloud in nature run

WIND ANALYSIS INCREMENTS IN 12-hr 4D-VAR



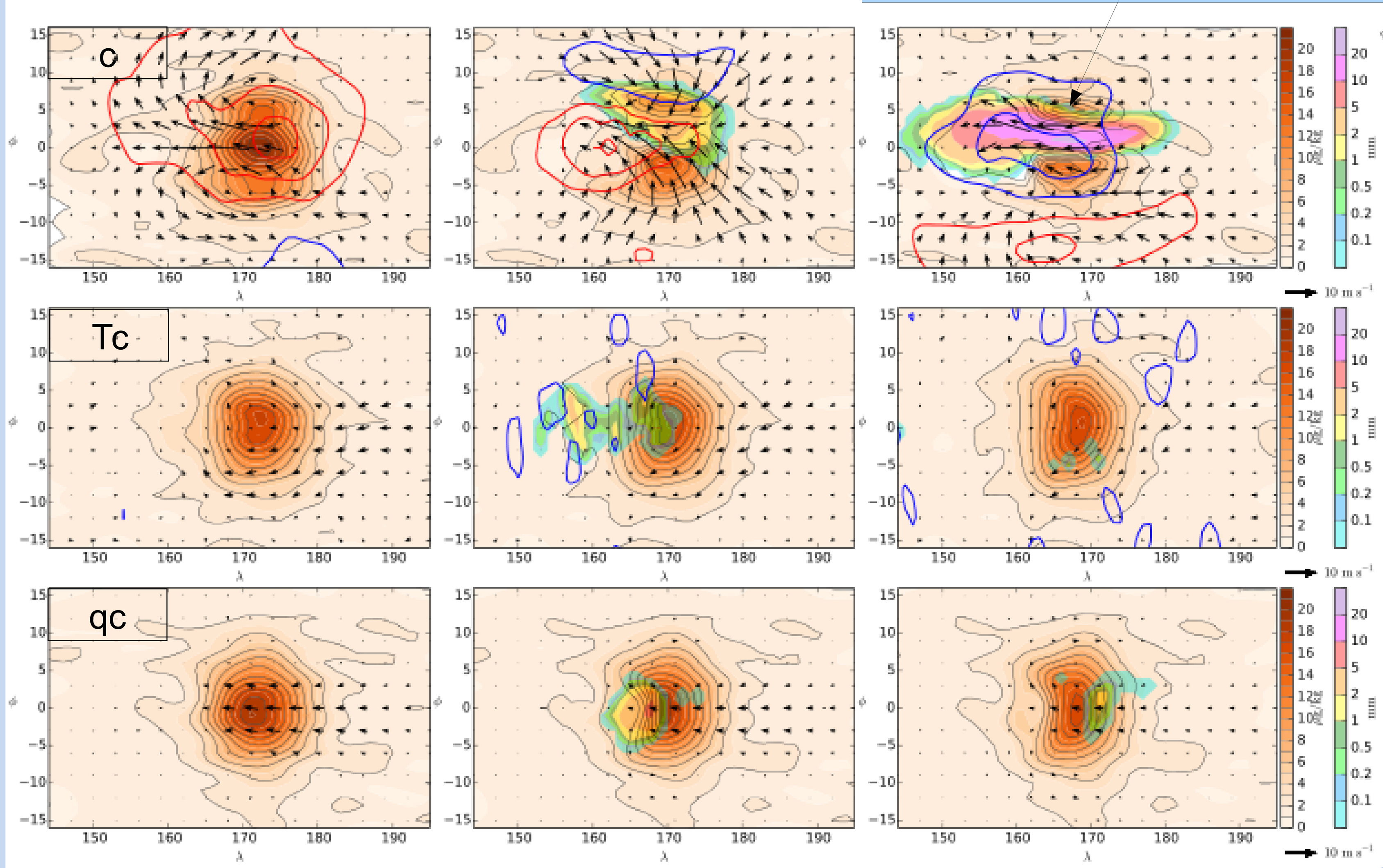
5 Wind retrieval in the moist atmosphere

Nature run - prior

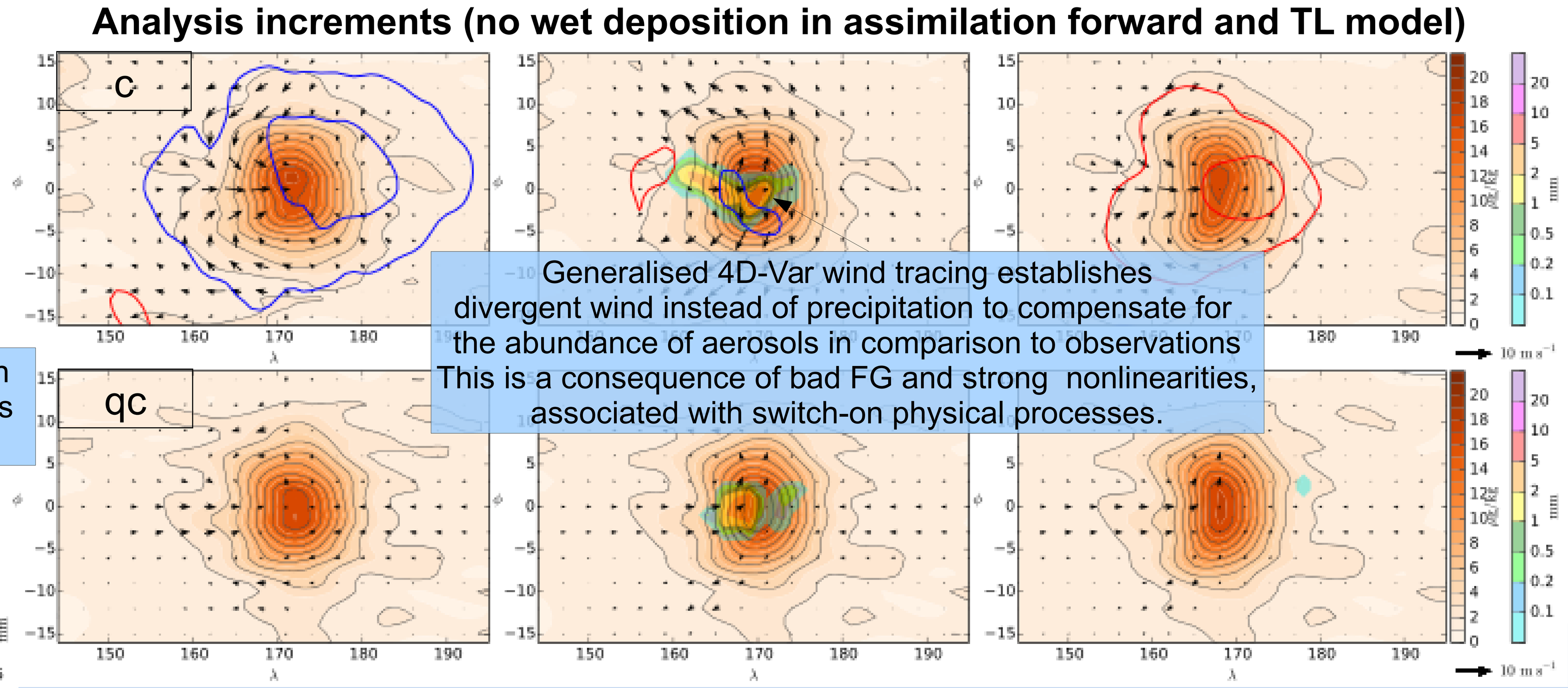


Analysis increments

Negative temperature increment at +12 h leads to numerical precipitation and ruins the aerosol analysis



Analysis increments (no wet deposition in assimilation forward and TL model)



Generalised 4D-Var wind tracing establishes divergent wind instead of precipitation to compensate for the abundance of aerosols in comparison to observations. This is a consequence of bad FG and strong nonlinearities, associated with switch-on physical processes.

6 Conclusions

- Wind tracing from 4D-Var assimilation of tracer observations is working well in the dry atmosphere, even in the case of strong non-linear flow.
- Wind tracing in the saturated atmosphere becomes very difficult due to non-linear nature of the aerosol-moisture interactions (here modelled by wet deposition)
- Challenge: In order to retrieve information about dynamics, all physical processes affecting the tracers need to be accurately known. Futhermore, the spin-up in form of excess moisture precipitation should be minimized. If the background wind is poorly known, the moist-convective processes are badly conditioned, leading to a wrong prediction of the aerosol-moisture interaction and spurious wind increments.

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