Variational assimilation of tropical cyclone position

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The Centre for Australian Weather and Climate Research
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Why Assimilate Cyclone Position?

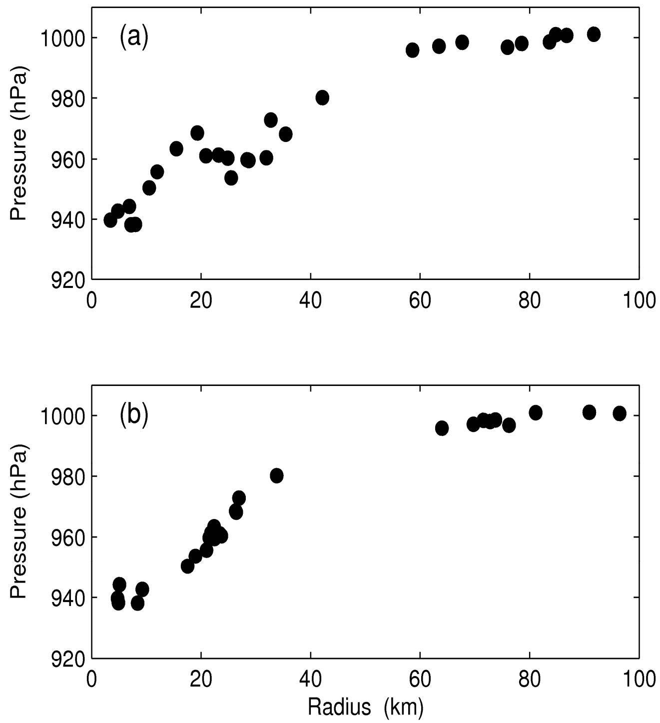
- Forecasters produce manual estimates of cyclone position and intensity every few hours.
- Volume of observations is small (few thousand per year) but impact of TCs is very high.
- Track is the most important TC forecast, good track forecasts require a good initial position.
- Current NWP systems either
  - ignore cyclone position estimates, or
  - use them to derive synthetic obs (“bogus”), which are assimilated normally.
- Bogus observations are widely used, but …
  - have correlated errors
  - may not represent structure of particular storm, including asymmetries
  - require much tuning for satisfactory performance
- Direct assimilation of cyclone position should be preferable

Finding the Cyclone Centre

- Cyclone position can be defined by, e.g.
  - minimum pressure
  - maximum vorticity
- Variational assimilation requires
  - observation operator, to estimate the observed value from the model state, and
  - tangent linear and adjoint of the obs operator
- Search for minimum pressure is not a suitable obs operator for VAR, because the search is not differentiable
  - but has been demonstrated in EnKF (Chen and Snyder 2008)

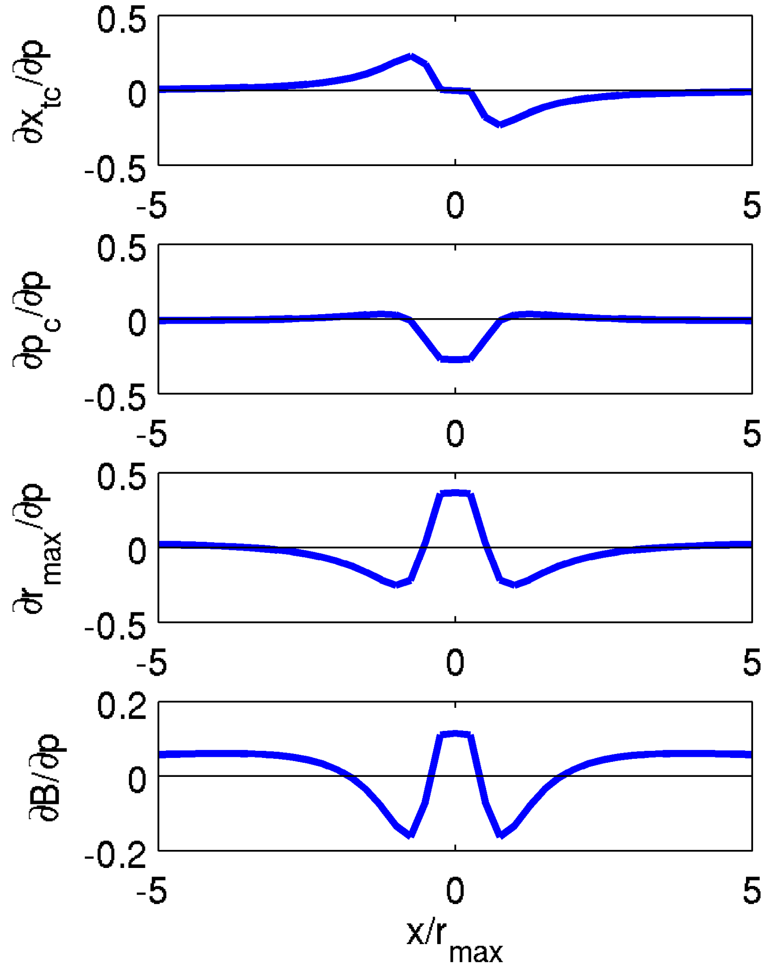
Iterative Centre Finder

- Tropical cyclones are well described by "parametric profiles", give the symmetric pressure as a function of a few parameters
  - e.g. $p = p_c + \Delta p \exp(-(r_{max}/r)^B)$
- The centre can be found by optimising a least-squares fit to such a profile (Kepert 2005 MWR).
  - Nonlinear least-squares fit of data to above curve.
  - Control variable = (p_c, r_{max}, B, position).
  - Estimates cyclone position and structure.
  - i.e. $H(\mathbf{p}) = (p_c, r_{max}, B, \text{position})$
- Originally designed for observations but also works on model data.
- Fig shows dropsonde data in Hurricane Georges, relative to official track (top) and relative to iterative centre (bottom).



Differentiating the centre-finder

- Derivative of one iteration is straightforward.
- The derivative of many iterations follows by the chain rule.
- Figure shows sensitivity of the diagnosed cyclone position, intensity, RMW and size to state pressure **p**.
    - i.e. the components of dH/d**p**.



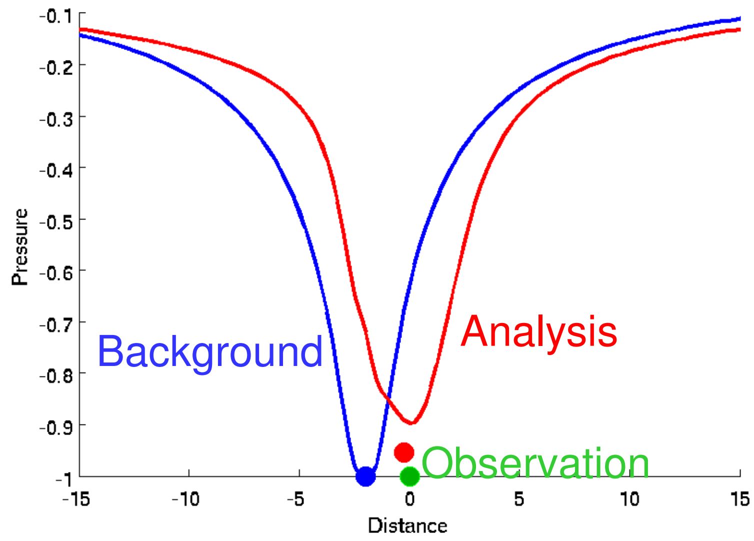
Assimilation test

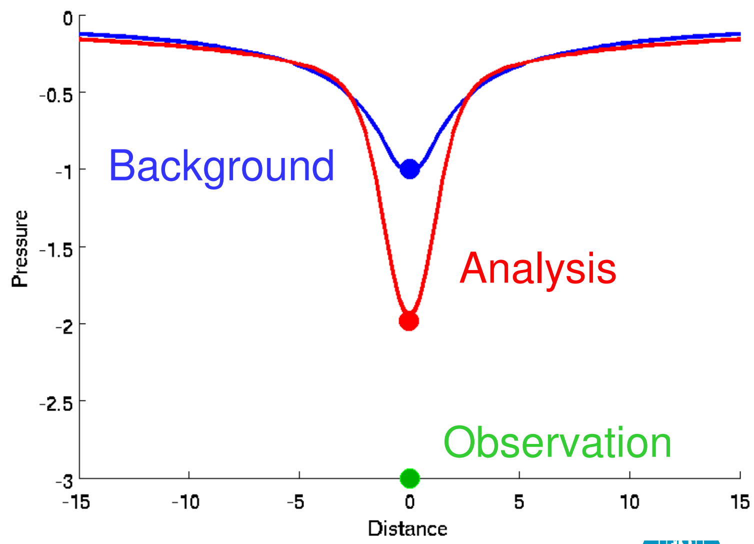
- Implemented in a simple 1-dimensional variational assimilation
  - Cyclic domain, univariate pressure analysis.
  - Analysis in spectral space, truncated at half-resolution.
  - Background error correlations Gaussian, length scale 1.
  - Background error 0.2.
  - “Inner loop” is fully linear, 15 iterations.
  - “Outer loop” contains iterative part of centre-finder, 3 iterations.
- Observation
  - Is of cyclone location, intensity, size and structure (x_{tc}, p_c, r_{max}, B).
  - Obs error matrix **R** assumed diagonal.
  - Obs error ($x_{tc} \rightarrow 0.2$, $p_c \rightarrow 1$, $r_{max} \rightarrow 0.5$, B $\rightarrow$ 1)
  - Can adjust **R** to e.g. give more weight to position estimate than to intensity.

Results 1

- Observation of cyclone location, intensity and scale alters entire state estimate.
- Curve shows state **p** (blue=background, red=analysis).
- Dots show diagnosed cyclone centre intensity and position H(**p**).
- Analysis can move cyclone (top) or change intensity (bottom).

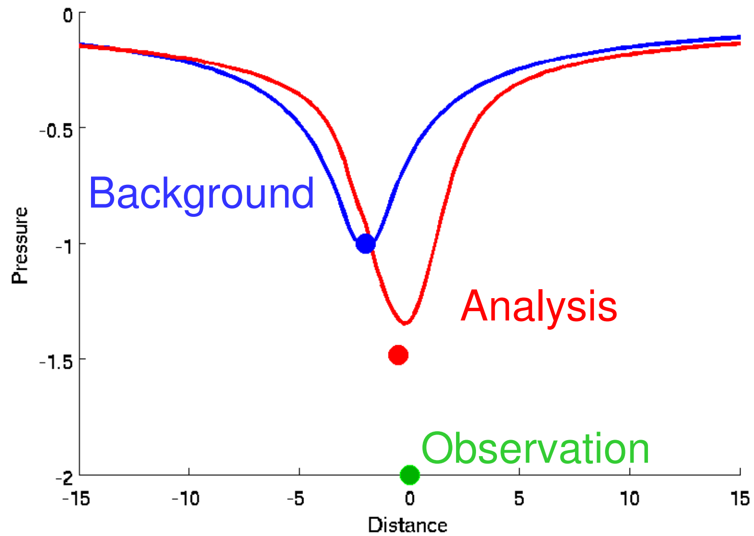
- Centre-finder tends to underestimate analysis intensity, introduces small bias (maybe fix with a weighting function?).

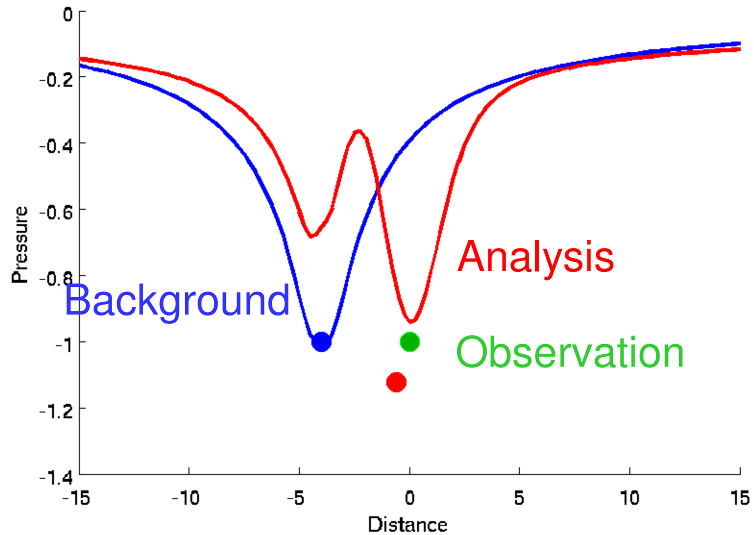




Results 2

- Scheme can also change the intensity and position together (top).
- Attempting to move the vortex “too far” can create a “double vortex” (bottom).
  - What is “too far” depends on **B**, **R**, etc.
- Bogussing schemes have a similar problem.





Discussion

- Direct variational assimilation of tropical cyclone position is possible (in test system)
  - Will it work in full 3d-var and 4d-var? (probably)
  - Will it outperform bogussing? (don't know, some issues to resolve)
  - Would need less tuning needed than bogussing.
- Works best when background position is "close" to observation.
- Some issues with nonlinearity of operator (not shown here)
  - An outer loop is helpful, probably essential in practice
- Volume of observations is small, so use of an (expensive) iterative obs operator doesn't matter.
  - The iterations are in the outer loop, anyway.
- Should also be useful for adjoint-based sensitivity studies
  - e.g. with a cost function that measures how close the cyclone went to Miami.

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Thank you

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